



The
Papua and New Guinea
Agricultural Journal

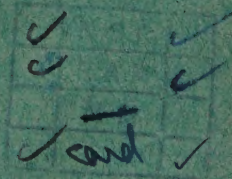
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Former Issues of Gazette and Journal

The following numbers of the *Agricultural Gazette* have been issued :

New Guinea Agricultural Gazette—

- Volume No. 1, Number 1.
- Volume No. 2, Numbers 1, 2 and 3.
- Volume No. 3, Numbers 1 and 2.
- Volume No. 4, Numbers 1, 2, 3 and 4.
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- Volume No. 6, Numbers 1, 2 and 3.
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- Volume No. 10, Numbers 1, 2, 3 and 4.
- Volume No. 11, Numbers 1, 2, 3 and 4.
- Volume No. 12, Numbers 1, 2, 3 and 4.
- Volume No. 13, Numbers 1, 2, 3 and 4.

Copies of all numbers of the *Gazette* to Volume 7, No. 4, are out of print.

SPACING AND SHADE TRIALS WITH CACAO

A. E. CHARLES *

INTRODUCTION

TWO of the most important factors affecting yield of cacao plantations are the spacing at which the trees are planted, and the overhead shade provided. Earlier recommendations made by the Department of Agriculture, Stock and Fisheries, such as those given by Henderson (1954), were based on observation and practical experience in cacao growing, but at the time there were few experimental data from which conclusions could be drawn. Since then, there has been considerable research, both in this country and overseas, and although results are still far from complete it has been felt desirable to review the findings for the benefit of local growers.

It must be recognized at the outset that there is no ideal spacing or shade system which can be universally applied wherever cacao is grown. There are so many different factors involved in determining what is best that the optimum must vary under different planting conditions. Because there is some interaction between shade and spacing (that is to say, the level of shade required may depend on the spacing of the trees) both are included together in this paper, although for the most part they will be discussed separately.

A. SPACING.

The optimum spacing will depend in the first place on the vigour of the trees. Thus, spacing for seedlings must be considered separately from spacing for fan cuttings, because of their different habit of growth. Different varieties of seedling cacao and different clones could also be expected to differ in their spacing requirements. Vigour of the trees will be affected by climate and soil type, so that spacing recommendations may need to be varied in different districts, and even within the same district where soil types differ. Nor is it evident from first principles whether spacing should be closer on poorer soils, because of reduced vigour, or wider to reduce competition for nutrients. Fertilizing will also affect tree vigour. The overhead shade also influences the vigour and habit of growth of the trees, while conversely the spacing affects the amount of self-shading in the cacao.

Secondly, there are economic considerations other than the production of maximum yield. Spacing influences the level of ground shade, which largely determines the amount of weed growth. Thus it has an important bearing on maintenance costs. Consideration also must be given to ease of access through the cacao stand, affecting costs of harvesting and pest and disease control operations.

Thirdly, consideration must be given to changes in the stand as the trees age. It might be expected that, as the trees grow, inter-tree competition would increase and a too dense stand would be at a disadvantage. On the other hand, there is always a proportion of trees which die out as the stand ages, and these losses might be less serious in an originally dense stand.

Overseas Experiments.

The spacings generally used vary greatly from country to country. Urquhart (1961) quotes the following as being favoured: Trinidad, 12 ft. x 12 ft.; Ceylon, New Guinea and Samoa, 15 ft. x 15 ft.; Congo, earlier 4m. x 4m., more recently 3m. x 3m.; West African peasant farmers, 3½ ft. x 4 ft. and more recently 5ft. x 5ft. The wide variation may be due in part to differences in varieties and types of planting material. Experiments in each country have tended to start from the standard for the locality, and as a result the ranges of spacings used do not always overlap.

Gordon (1954) studied 269 quarter-acre plots of farmer-planted cacao of varying density at Tafo, Ghana. He concluded that a density of 300 to 400 trees per acre might be a natural optimum for local conditions. This density was achieved by random close planting, allowing the trees to thin themselves as they matured. Between the range of 270 and 670 trees per acre there was no great variation in yield.

A trial was planted in 1947 at the West African Cacao Research Institute at Tafo (Anon., 1949) with unselected Amelonado seedlings at eight spacings ranging from 15ft. x 15ft. to 4ft. x 4ft. (200 to 2,800 trees/acre). In the first two years' bearing of these trees yields were highest at the widest spacings, but so also was

* Agronomist, Lowlands Agricultural Experiment Station, Keravat, New Britain.

weed growth and capsid damage (Benstead and Wickens, 1955). Published results up to 1959 (Smith, 1960) do not show any exact correlation between spacing and yield, although numbers of pods per tree have been consistently higher at wider spacings. Highest yield per acre (considering totals up to 1959) has been obtained at 7½ ft. x 7½ ft. (774 trees/acre), with yields falling off consistently at wider spacings though not so consistently at closer spacings. It should be noted that there has been no tendency for the optimum to move towards wider spacings as the trees age, but rather the reverse.

A second trial at Tafo, with Upper Amazonian cacao was planted in 1949-50, with three spacings (8 ft. x 8 ft., 10 ft. x 10 ft., 12 ft. x 12 ft.). Smith (1960) reported that no conclusions could yet be drawn, though the 10-foot spacing had given highest yields in the two years 1957-59.

In Nigeria, a trial was planted in 1941 with Trinitario and Amelonado cacao in alternate rows, at spacings from 5 ft. x 5 ft. up to 15 ft. x 15 ft. Kowal (1959a) states that the trees had fully developed eight years after planting, but the canopy was still open at 12 ft. x 12 ft. and 15 ft. x 15 ft. spacings. Trees were taller at close spacings, and capsid infestation was much lower. By 1956, 32 per cent. of the original trees were missing, but there was no clear relation between spacing and tree survival.

The effect of stand density on yield per acre differed for the two varieties. With Trinitario there was a linear increase in yield with increasing density of stand, maximum yield being obtained at the closest spacing (1,020 trees/acre actual stand). Amelonado, however, showed a clear optimum at about 800 trees/acre, with yield declining at greater densities than this as well as at lower. Both varieties commenced bearing earlier at the closer spacings. The author concludes that, in Nigeria, for either variety a stand density of less than 580 trees/acre is disadvantageous in relation to health and management and uneconomic in relation to yield. He found also (Kowal, 1959b) that there was a strong correlation between stand density and soil moisture, soil nitrates, organic litter and soil nutrient status. This experiment was apparently conducted under rather unfavourable conditions, since the average annual yield of all plots from 7th to 14th year of age was only 160 lb. dry cocoa per acre.

In the Congo, Vallaeys (1954) noted that in an experiment at Yangambi, over a period of 14 years, the closest spacings (520 to 650 trees per acre) gave earlier bearing and sustained higher yields.

Trials in Trinidad have used clonal material, not seedlings. Up to nine years of age, higher yields were obtained at 8 ft. x 8 ft. than at 12 ft. x 12 ft. spacings (Maliphant, 1959a and 1959b).

Table I.—Numbers of Pods Harvested in Cacao Shade—Spacing Observation Block.

	12-FOOT TRIANGLE				15-FOOT TRIANGLE			
	SHADED		UNSHADED		SHADED		UNSHADED	
	Pods/tree	Pods/acre	Pods/tree	Pods/acre	Pods/tree	Pods/acre	Pods/tree	Pods/acre
1953-54	14.4	5,027	28.5	9,928	18.8	4,220	31.7	7,102
1954-55	28.1	9,782	47.0	16,422	26.4	5,915	58.9	13,210
1955-56	21.9	7,610	37.9	13,262	24.8	5,561	45.0	10,092
1956-57	45.5	15,840	56.5	19,757	54.8	12,286	66.5	14,915
1957-58	29.4	10,244	26.0	9,073	39.8	8,920	39.1	8,760
1958-59	44.7	15,543	34.0	11,882	65.0	14,570	57.3	12,854
1959-60*	44.9	15,628	61.2	21,403	70.5	15,796	68.2	15,284
				(20,275)				(14,400)
1960-61*	36.3	12,639	39.6	13,832	52.8	11,842	49.9	11,175
				(12,145)				(9,420)
TOTAL	265.2	92,313	330.7	115,559	352.9	79,110	416.6	93,392

12-ft. plots Total yield—103,936 pods/acre.

15-ft. plots Total yield—86,251 pods/acre.

Shaded plots Total yield—85,711 pods/acre.

Unshaded plots Total yield—104,475 pods/acre.

* Figures in brackets for the unshaded plots have been adjusted to remove fertilizer effects.

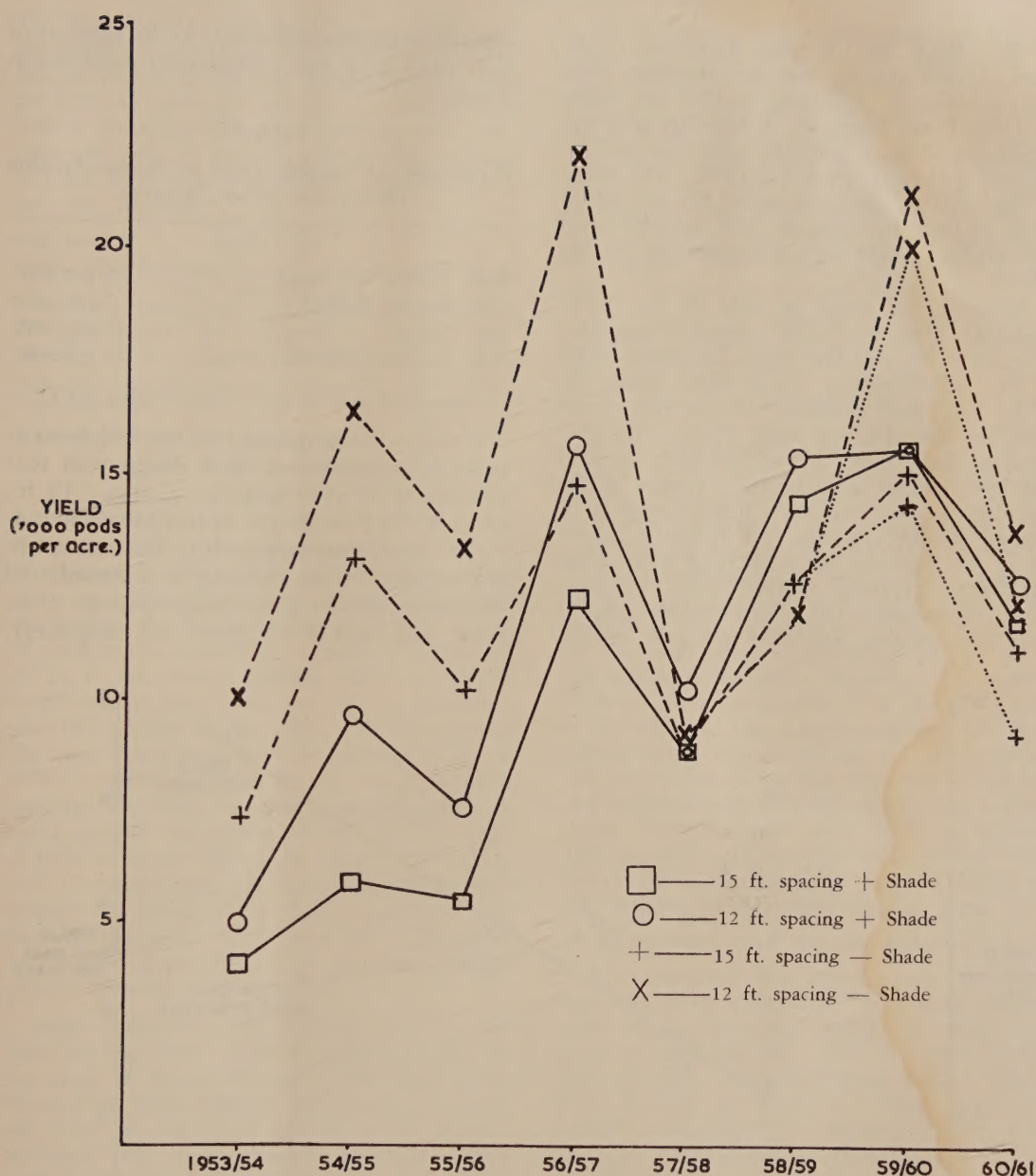


Fig. 1.—Yields in Cacao Shade—Spacing Observational Trial Block, Keravat.

Note.—Dotted lines for yields of no-shade plots 1959/61 indicated estimated yields in absence of fertilizer.

Local Experiments and Observations.

An observational block was planted at Keravat in early 1949 to compare 12 ft. triangular spacing (348 trees/acre) with the standard 15 ft. triangle (224 trees/acre) and also

to compare the performance of cacao from which all permanent shade was removed at maturity with normally-shaded cacao. This block, of seven acres, contained eight replicates of a progeny trial, four spaced at 12 ft. and four at

15 ft. Shade was removed from two replicates of each spacing, but the treatments were not randomized. Yields up to 1961 are shown in Table I and Figure 1. A fertilizer trial was superimposed as a split-plot treatment on the progeny trial replicates in late 1958. The effects of this will be discussed under the section on shade as there has been no clear indication that the fertilizer would have influenced the spacing effects.

Although the trend in yield of the 12-ft. unshaded block has been somewhat irregular, it seems quite clear that yields have been better at the closer spacing. Over eight years, the 12-ft. plots have produced 17 per cent. more pods per acre than the 15-ft. plots in the presence of shade, while without shade 12 ft. yield has been 25 per cent. higher. Vigour of the trees has been sufficient for a closed canopy to be formed at both spacings, and in fact a gap of 20 ft. left between the 12-ft. and 15-ft. plots has been completely covered over. In June, 1961, approximately 10 per cent. of the original trees were missing, and there are quite marked

differences between treatments in the numbers of trees which have died. Mortalities are shown in Table II.

Table II.

Percentages of Missing Trees in Shade—Spacing Observation Block, Keravat.

		Missing Trees
12-ft. Spacing + Shade	....	5 per cent.
12-ft. Spacing Unshaded	....	7 per cent.
15-ft. Spacing + Shade	....	12 per cent.
15-ft. Spacing Unshaded	....	18 per cent.

(Recorded as at 30.6.61—Trees 12 years old.)

A more accurate spacing trial was laid down in 1956, in a randomized block design with four replications of five triangular spacings: 12 ft., 15 ft., 17 ft. 2 in., 20 ft., 24 ft. (348, 224, 174, 126, 87 trees/acre respectively). This was extended in 1957 by the planting of a second trial with four replicates of two hedge spacings, 24 ft. x 6 ft. and 18 ft. x 8 ft. (both 303 trees/acre).

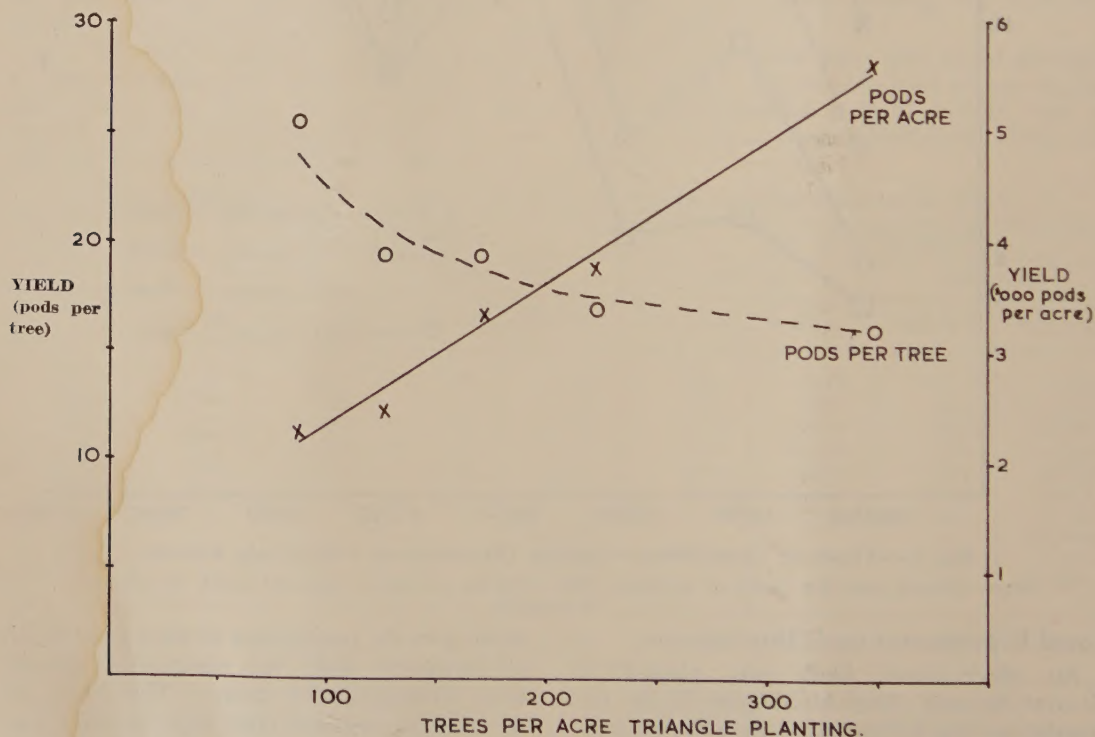


Fig. 2.—Cacao Seedling Spacing Trial. Yield to 4 years of age.

The first year's yield records are available from the triangular plantings, and are shown in Table III and Figure 2. The relationship between yield per acre and trees per acre gives a straight line with a correlation between pods per acre and trees per acre of 0.955. Thus yields per acre increase with density of stand, although yields per tree decrease.

Table III.

Cacao Spacing Trial, Keravat. Pod Yields up to Four Years of Age.

Trees per acre	348	224	174	126	87
Spacing	12 ft.	15 ft.	17 ft. 2 in.	20 ft.	24 ft.
Pods per acre	5,578	3,765	3,302	2,439	2,215
Pods per tree	16	17	19	19	25

Minimum difference for significance :

5 per cent. = 1,081 pods per acre.

1 per cent. = 1,518 pods per acre.

Differences in weed growth under the different spacing were quite pronounced. At 12 ft. spacing, by the end of 1960 (four years of age) the cacao had formed a closed canopy and the ground was covered with a complete mulch of dead leaves, preventing virtually all regrowth. At 15 ft. the canopy had not closed completely by the end of June, 1961, and some weed growth was still present in the plots. At this spacing the trees would take about 12 months longer to form a closed canopy. In the wider triangle spacings the trees remained quite separate and weed growth was inhibited only in the circle directly under the trees. In the hedge spacing, still 12 months younger, the trees intermingled within the hedge rows, but a gap remained between the rows. Thus there was a line clean of weeds under the cacao but considerable growth between the rows.

Some difference was evident also in the habit of the trees. This is influenced also by the level of shade and under the fairly heavy shade level maintained for young cacao at Keravat most of the trees tended to be upright in habit even at the widest spacings. There were a few trees, however, in which the branches tended to droop to the ground, and this hinders access for harvesting. It has been observed in other plantations, particularly where cacao is grown under coconuts, that this tendency to droop is much more pronounced, and it may be that it increases with age of the trees. By contrast, in the 12-ft. plots of this trial, and generally at Keravat where the trees have formed

a closed canopy, self-shading forces growth upwards and drooping is virtually eliminated. It is the practice at Keravat to prune the trees once they have reached maturity to remove any limbs which hinder access, and under the closed canopy this proves permanently effective. It has been observed on other plantations that similar pruning of trees where the canopy is open has been less effective, probably because there is not the support from intermingled branches, and regrowth at low levels is not shaded out.

In addition to these trials with seedlings, a spacing trial with cuttings was planted in 1957, with two replications of five spacings: 9 ft., 11 ft. 6 in. and 14 ft. triangular, and 18 ft. x 6 ft. and 18 ft. x 4 ft. hedge. This trial is only just coming into bearing, so that little can be said about yields, though it may be noted that in the first few months highest per acre yield has come from the closest spacing. At four years of age, in all triangular spacings the branches intermingle so that access is difficult. Even in the hedge spacings, although it is easy enough to walk between the rows, approach to the trees for harvesting is hindered by a mass of low-hanging branches. However, in another block of clonal cacao planted at 12 ft. x 12 ft., at five years of age it appears that earlier difficulty of access is now passing off. Self-shading and competition is forcing new growth upwards and causing lower branches to die, so that access is now fairly easy and seems likely to improve. This has not occurred with certain clones which have a rather straggly habit, but such clones are not likely to be used commercially.

Discussion and Recommendations.

It is significant that almost every experiment that has been conducted has shown highest yields at close spacings, usually closer than standard recommendations. The inference is that cacao probably performs best at a stand density that has the appearance of being excessively crowded. It should be remembered that most of these trials are still in their early years, and the optimum may change later. However, there is little in the results reported to suggest this. In the Tafo trial, any change in the optimum has been towards narrower rather than wider spacings. In the Keravat observation trial the initial advantage of the 12-ft. plots does seem to have declined, but there is no sign that the 15-ft. plots are likely to overtake them to the extent of ultimately giving a higher total yield.



Plate I.—Seedling cacao, 4 years, 9 months age, 12-ft. triangle spacing.
(The ground under the trees is completely covered with a mulch of dead leaves, and weed growth eliminated. Growth of the trees is entirely upright.)



Plate II.—Seedling cacao, 4 years, 9 months age, 15-ft. triangle spacing.
(Leaf mulch covers the ground only in parts of the plot. One tree in left background is drooping to the ground.)



Plate III.—Seedling cacao, 4 years, 9 months age, 24-ft. triangle spacing.
(Trees are quite separate, some droop to the ground and weed growth is abundant.)



Plate IV.—Seedling cacao, 3 years, 11 months age, 18-ft. hedge spacing.
(Trees meet within the rows but not across the rows. Leaf mulch is present only immediately under the trees.)

The results of the West African trials could not be transposed directly to Papua-New Guinea. Yields in Nigeria are low, and growth not sufficient for a closed canopy to form even at 12-ft. spacing, which indicate that the trees in this trial are much less vigorous than trees at Keravat. In Tafo, too, although yields are higher than in Nigeria the optimum yield of 4,500 lb./acre up to 12 years of age is only about half the yield of the 12-ft. plots at Keravat up to the same age. Probably growing conditions are not as good as at Keravat, and it is likely that as a general principle closer spacings are required under poorer conditions, although the experimental evidence is not yet sufficient to establish this conclusively. Kowal (1959*b*) states that it is generally accepted in Nigeria that good health, growth and performance of cacao is incompatible with the encroachment of grass/weed ground cover. The most important, or at least the easiest, method of controlling ground cover is by the establishment of a closed canopy. Thus, if Kowal is correct, this points clearly to the need for closer planting on poorer soils. There is no evidence yet from the Keravat spacing trial to support the need for a closed canopy, as trees still look quite healthy even at the widest spacings, but this is to be expected when the trees are only five years old. General observation on older cacao in New Britain does suggest that trees do not perform so well where the canopy is not closed.

Considering the factors involved as they were set out in the introduction, the following conclusions may be drawn: for productivity, 12 ft. spacing is to be preferred to 15 ft. for seedling cacao in the Gazelle Peninsula. In districts where soils are less fertile, spacings even closer than 12 ft. may be desirable. Twelve-foot spacings are to be favoured also for reduced maintenance costs, as a closed canopy is formed earlier and shades out the grass. Access is also facilitated in a stand where the canopy has closed, since lower growth is shaded out, although a tendency to taller growth of the trees may be some disadvantage for harvesting. In regard to hedge plantings, insufficient experience has been had for conclusions to be reached. However, there does seem some danger that the wide spacing between rows, through delaying the formation of a closed canopy, may allow branches to droop to the ground and thus hinder rather than assist access. Finally, considering changes in the stand as the trees age, there is some evidence

from Keravat of higher mortality at 15 ft. than at 12 ft., so that again closer planting is favoured.

On present evidence, therefore, it seems clear that the recommendation for spacing of seedling cacao in the Territory should be changed to 12 ft. on the triangle, rather than 15 ft.

B. SHADE.

In the wild state, cacao is an under-story tree of dense, tropical rain forest, and is thus capable of, and adapted to, growth under heavy shade. However, like any other plant, it requires light for photosynthesis (the process by which the leaves manufacture carbohydrates, which are the main raw materials for growth and pod production). Consequently, too dense shade limits photosynthesis and thereby retards growth and reduces productivity. At the other extreme, the tree appears unable to stand full exposure to direct sunlight without ill effects. The aim in using overhead shade is to strike a balance where productivity is at a maximum but health of the tree is unimpaired.

Urquhart (1961) states that "although there is some difference of opinion as regards the extent to which the cocoa tree needs shade after it has grown and produced a canopy, there is universal agreement on the need for shade at the seedling stage and in the first few years of the life of the tree." This has been accepted without question by the Department of Agriculture, Stock and Fisheries, and is fully borne out by observations on occasional seedlings which have been seen growing without shade. However, there is still room for inquiry into the intensity of shade required in the early stages, as well as in the later stages. The changing requirement as the tree ages is probably due primarily to increase in self-shading, though other factors also may be involved.

The effects of shade are complex. Overhead shade affects not only the illumination of the cacao trees, but also such things as air temperature, soil temperature, wind and air movements (and possibly movement of pollinating agents) and humidity. Many different tree species are used for shade, and these may differ in their secondary effects if not in their primary effects. The roots of shade trees must compete with the cacao to some extent for water and nutrients, although it might be expected that a leguminous species would add nitrogen to the soil through fixation from the atmosphere. A

shade tree which is deeper rooted than the cacao could perhaps bring up nutrients from lower levels and make them available through leaf fall. Because of all these things, shading will interact with such factors as spacing and fertilizing, and shade requirements will vary according to climate and weather pattern.

As with spacing, long-term effects must also be considered. Removal of shade from mature cacao generally boosts production initially, but we need to know whether this is only temporary and whether under full light the trees may "burn out" prematurely. Vallaeys (1954) quotes reports from several countries indicating that the life of the cacao tree is reduced in the absence of shade.

Overseas Experiments.

A fundamental study of shade effects on cacao was laid down at the Imperial College of Tropical Agriculture, Trinidad, in 1950 (Evans and Murray 1953). Clonal cuttings were grown under artificial shade with light intensities ranging from 15 per cent. to 100 per cent. The general conclusions from this trial were summarized by Murray (1955). Under heavy shade, plants were insecurely rooted and of spreading habit, while under little or no shade they were stronger and more bushy in habit. Under shade, total leaf area was greater and individual leaves larger. Relative growth rate of the plants, in the absence of fertilizer, was found to be highest at about 50 per cent. light, decreasing above and below this. One of the most significant features of the trial was an interaction between shade and fertilizer, particularly nitrogen, there being little fertilizer response under heavy shade but marked response under light shade. Thus, highest yields were obtained from fertilizer plots under light shade. Murray states, however, that even with high nutrition shading appears to be necessary in the early stages until the plant is big enough to provide self-shading.

A similar experiment was laid down at Yangambi, Congo, in 1955 (van Himme and Petit 1957), again using clonal material under artificial shade. Effects on early growth were similar to those at Trinidad, and it was noted that the optimum light intensity shifted from 25 per cent. in the first year to 75 per cent. in the second year of growth. This again points to the requirement of heavier shade in the early stages.

In a field experiment planted at River Estate, Trinidad, in 1949 (Havord 1953) yields up to 1958 were about 10 per cent. higher in the absence of permanent shade, and fertilizer response was greater (Malipant 1959b). From West Africa, Cunningham (1959, 1960) reports a trial on 10-year-old Amelonado seedling cacao spaced at 8 ft. x 8 ft. under *Gliricidia* shade. Shade was removed from half the plots and a mixed fertilizer applied to half the plots. There was a marked response to the treatments in the first year, and even more in the second year. Response to fertilizer under shade was slight (20 per cent.) but shade removal gave an increase of 150 per cent. in yield, and shade removal plus fertilizer gave an increase of 220 per cent. with the phenomenal yield of 3,091 lb. dry cocoa per acre.

Local Experiments and Observations.

Concerning shade species, little can be added to the comments of Henderson (1954) who compared several species and listed *Leucaena glauca* and coconuts as the most satisfactory for local conditions. These two species are almost the only ones now used in this Territory. Recently some introduced strains of *Leucaena glauca* have been tested by the Department, and have proved more vigorous than the local strain in all localities so far tried. In observation plots at Keravat average height of seedling five months after transplanting were: local strain, 7.4 ft.; Peru, 8.5 ft.; El Salvador, 9.0 ft.; Guatemala, 11.0 ft. The introduced strains are a rather darker green and do not seed as freely as the local. In another small plot about three years old, the Guatemala strain is 10 ft. to 15 ft. taller than local strain of the same age, and the trees are generally stouter and more vigorous.

The main shade experiments at Keravat have been concerned with the shade requirements of mature cacao. The observation block whose yields are shown in Table I and Figure 1 includes two plots from which all permanent shade was removed gradually as the trees approached maturity. The plots were planted early in 1949 and differential shade removal was commenced in March, 1953, and completed in May, 1954. Shade on the remaining two plots was at this time at what was then considered normal (i.e., approximately 15 ft. spacing of the *Leucaena* trees). In 1957, the shade on these plots was further thinned to about half this level.



Plate V.—Young cacao tree showing effects of too heavy shade.
(Ramification is high, branches are long and spindly and leaves large.)



Plate VI.—Young cacao tree under satisfactory shade.
(This tree is the same age as that in Plate V.)

The results indicate that shade removal caused a large initial boost in productivity, followed by a decline, evident first in 1957-58. However, the rapidity of this decline is probably exaggerated in the graph, since in the same year the yield of the control plots was boosted by shade thinning (this boost was evident through comparison with another block under normal shade, in which 57-58 yields were lower than those of 55-56). The trends since 1958 have been complicated by an apparent interaction between spacing and shade, the unshaded plots at 12-ft. spacing showing a marked burst of productivity in 1959-60 which has been only partially maintained in 1960-61. At 15 ft. spacing, the unshaded plots have continued to give lower yields. Interpretation of the trends

in the past two years is not so certain, because the superimposed fertilizer trial appears to have caused yield improvement only in the unshaded plots. The response has not been consistent, and therefore not statistically significant, but by analogy with results reported from overseas it may be assumed to be valid. Accordingly, the trends without fertilizer (based on yields of the control plots) are indicated in the graph by dotted lines. It will be seen that this does not alter the general picture very significantly.

The effects of shade removal on the appearance of the trees has been reduction in leaf size but increase in leaf number, a general tendency to a paler green colour, shortening of the internodes, and some tip die-back at the tops of the trees. The overall impression is that trees with-



Plate VII.—Young cacao tree showing symptoms of insufficient shade.
(Ramification is low, growth is very bushy, leaves are small. This tree is older than those in Plates V and VI.)



Plate VIII.—Unshaded cacao in Observation Plot at Keravat.
(Some tip die-back is evident at the tops of the trees.)

out shade look appreciably less healthy than trees under shade and from their appearance it had been expected that productivity would decline earlier and more severely than it did. After seven years without shade, some trees show severe effects, being largely defoliated, but most are only mildly affected. The tendency is more pronounced at 15 ft. spacing than at 12 ft. It may be seen from Table II that there have been more deaths in the unshaded plots than in the shaded.

A more comprehensive shade trial was commenced in 1957 on another block of seedling cacao which had been planted in 1948 at 15-ft. triangle and raised under normal *Leucaena* shade. Between October, 1957, and January, 1959, shade was reduced on certain plots to give four levels—normal (15-ft. triangle spacing of *Leucaena*), half normal, quarter

normal, nil. The design of the trial is a randomized block with four replications, and plot size is 130 trees including guards. Individual yield records have been kept for all trees since 1953, and the level of guarding required between plots was determined by comparing shade effects in different zones from the outside to the centre, of the 1959-1960 yields. It appeared that 30 ft. guarding might be adequate, but to be on the safe side results have been assessed on the yields of an inner plot of 35 trees surrounded by 40-ft. guards having the same shade treatment. Yields for 1959-60 and 1960-61, adjusted by covariance analysis for pretreatment yield, are shown in Table IV and Figure 3. It may be seen that so far yield has been about 70 per cent. higher with no shade than with normal, with a clear negative correlation between yield and shade density.

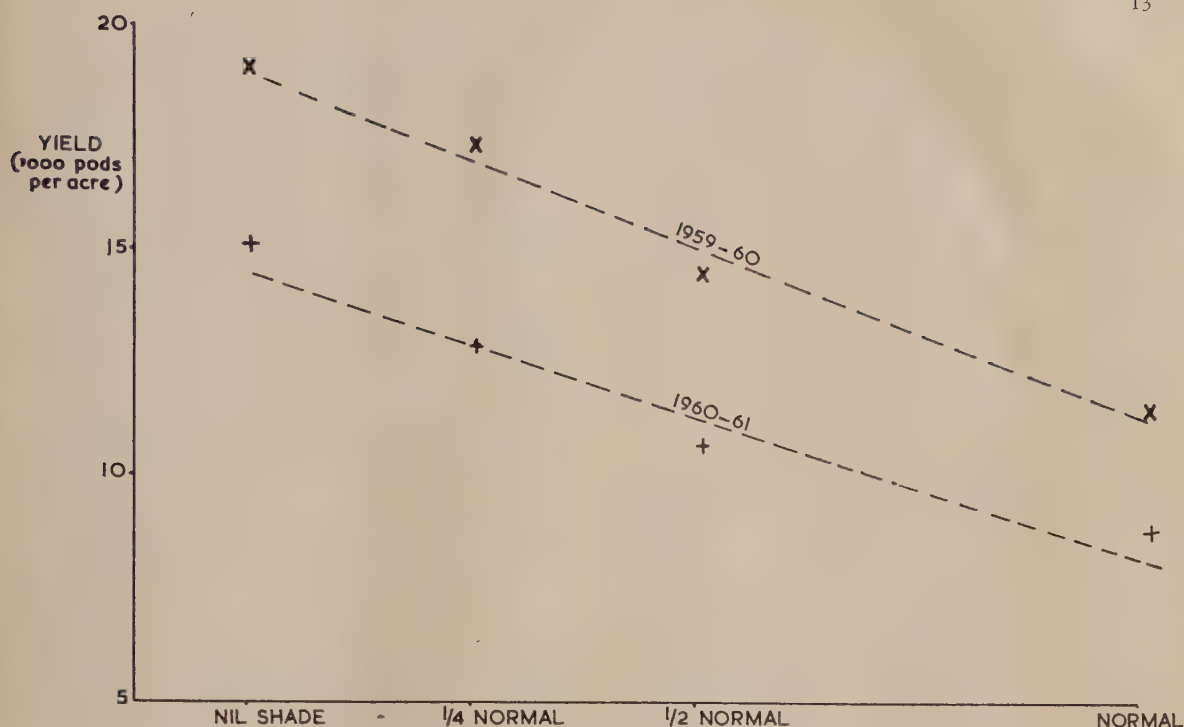


Fig. 3.—Cacao Shade Trial, Keravat, yields 1959 to 1961.

Table IV.

Pods Harvested in Cacao Shade Trial, Keravat.
Yield—Pods per acre.

	Nil shade	1/4 Normal	1/2 Normal	Normal
1959-60	19,021	17,338	14,643	11,475
1960-61	15,194	12,941	10,714	8,794

Note.—Yield adjusted for pretreatment yield.

It should be noted that in both these trials the cacao canopy is closed, so that there is a large amount of self-shading. Observations on other cacao in New Britain indicate that where the canopy is not closed trees show more pronounced yellowing and die-back symptoms even when light shade is present. This is particularly evident in some stands of cacao growing under coconuts, where many 10- to 12-year-old trees appear to be dying. Quite spectacular improvement in appearance has been obtained on similar cacao given heavy dressings of nitrogenous fertilizer (up to 1 lb. nitrogen per tree). The effect in the Keravat fertilizer trial has been less spectacular, but perhaps mainly because the original condition of the trees was not so poor.

Discussion and Recommendations

Further information will be needed before clear-cut recommendations can be made about shade requirements of mature cacao. This applies particularly to fertilizer-shade interaction effects. There is no doubt that nitrogenous fertilizers have greater effect in the absence of shade, and the symptoms of insufficient shade seem virtually identical with the symptoms of nitrogen deficiency. It may be that the ill effects of excess sunlight result primarily from an upset in the tree's food supply. Increased photosynthesis produces more carbohydrate, and this is utilized in the production of more pods. However, although carbohydrate is the major material used in growth of pods, it has to be balanced with small quantities of nutrients, especially nitrogen. Thus the tree draws more heavily on nutrients from the soil, and deficiency symptoms may appear unless fertilizer is used. However, it is not yet established that this is a complete explanation of the harmful effects of excess sunlight. Experimental results are not sufficient to show to what extent application of nitrogen can take the place of external shade, nor whether

this would be economic. Growers are cautioned against drawing conclusions from short-term effects, as early results may not be maintained later. For the present, it is recommended that light overhead shade should be maintained for all mature cacao. However, it does appear that a shade density sufficient to prevent all signs of leaf yellowing and tip die-back causes reduced yields. It may be that a stand of cacao producing at its maximum will always show slight symptoms of this type, but they do not seem to be inconsistent with continued tree health. Where such symptoms are only slight, responses to nitrogenous fertilizer so far have not been very great.

Apart from the question of nutrition, all the observations of the author indicate that the amount of external shading must be considered in conjunction with the amount of internal, or self, shading. Where the trees do not meet, it is probably that quite heavy external shade will be necessary to maintain the health and productivity of the trees. Where there is a closed canopy only light external shading is necessary.

The desirability of a closed canopy obviously points to closer spacings. However, perhaps more important, though not so obvious, is that it points to a need for fairly heavy shade in the early years. Several of the overseas experiments quoted have shown the influence of shade level on habit of growth, growth being more spreading under heavy shade. If shade is too light in the early years the trees become bushy and somewhat stunted, and therefore do not cover such a large area. Under heavier shade they grow outwards and much more quickly form a closed canopy. This may slightly retard the trees for productivity, but it has considerable economic advantage in that grass and weed growth is much reduced through the whole establishment period. Most of the difficulty growers experience with excess *Leucaena* seedling regrowth would be eliminated if the ground were kept constantly shaded in this way.

For the present, the following recommendations would be made for cacao establishment. For the first 12 to 18 months the shade canopy should be thick enough to prevent almost all direct sunlight from reaching the seedling, yet not so thick that the seedlings become leggy. Henderson (1954) sets out detailed recommendations of methods of establishment of shade of this type, which have been quoted in full by

Urquhart (1961). After about the first year, shade should be thinned slightly during the wet season, so that about 25 per cent. of direct sunlight passes through when the sun is overhead. With *Leucaena* this amount of shading will be found when the trees are close enough for their branches to meet and overlap slightly, the feathery nature of the foliage still permitting some sunlight to pass through. Shade intensity should be kept at about this level until the cacao trees meet and start to form a closed canopy. However, as the *Leucaena* will still be growing rapidly throughout this period thinning will have to be continued—20 per cent. to 25 per cent. of the trees remaining could be removed every wet season. This figure should not be accepted arbitrarily, as the requirement will depend on the vigor of the *Leucaena* in the particular locality concerned. Once the cacao trees are meeting shade thinning should be more intense, but nevertheless should not be too rapid. The aim should be to reduce shade over about two years until 70 per cent. to 80 per cent. of full sunlight is admitted. The shade trees will then be quite separate, but as they will continue to expand slowly further light thinning may be required in later years, possibly in the form of removal of individual branches rather than whole trees.

CONCLUSION.

As has been stated, firm recommendations cannot yet be made, particularly in respect of shade, as the basic principles involved are not yet clear. In order to gain further information, the following trials are to be commenced at Keravat :

- (a) a spacing trial covering spacings closer than 12-foot triangle.
- (b) a fertilizer trial to be superimposed on the existing shade trial, to find the effect of added nitrogen at different levels of shade.
- (c) a shade x spacing x fertilizer trial to test interaction of all three factors.

It is hoped that these trials will fill in many of the gaps in our present knowledge and ultimately enable detailed recommendations to be made for all three factors.

SUMMARY.

Spacing—West African trials have shown optimum yields at close spacing ($7\frac{1}{2}$ ft. or less). In an observation plot at Keravat, cacao at 12-ft. triangle outyielded acaco at 15-ft. triangle up

to 12 years of age. In a replicated trial with spacing from 12-ft. up to 24-ft. triangle, yield in the first year was highest at the closest spacing, and weed growth was much lower. It is recommended that 12-ft. spacing should be used in this Territory.

Shade—Experiments in Trinidad and West Africa have shown that the level of shade affects habit and rate of growth, and that responses to fertilizer are greater in the absence of shade. In an observation plot at Keravat, removal of shade from cacao at maturity caused greatly increased yields at first, but yield later declined to less than that of shaded plots. The effect differed at different spacings. In another trial with four levels of shade, yield in the first two years increased linearly with decreasing shade. Nitrogen fertilizer has given response only in the absence of shade. Further information will be required before definite recommendations can be made.

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CLONAL CACAO AT KERA VAT—Part II*

BY I. L. EDWARD.†

As noted in Part I the vegetative propagation of cacao trees selected for high yielding and quality attributes offers the quickest method of making improved planting material available to the planter. This paper is concerned with details of propagation experiments carried out at Keravat since 1955 and includes a summary of the methods in use at present.

Introduction

IF clonal cacao is to be planted on any appreciable scale in this Territory, it is apparent that apart from the initial introduction of material from Keravat, the planter will have to produce his own rooted cuttings. This is mainly necessary because of transport difficulties and expense. In the light of overseas experience there seems to be no insurmountable reasons why this could not be done eventually even though, for the present, this work will still be handled by the Department of Agriculture, Stock and Fisheries.

However, it is clear that the method at present employed is not entirely suitable for private production, although each of the factors and interactions discussed will be operative regardless of the method finally employed. Planters are urged not to rush into vegetative propagation of cacao until—

(i) they have secured from Keravat supplies of proven suitable planting material with which they have established material nurseries; and

(ii) a more simplified technique is available.

Work on establishing a more simplified technique is continuing.

Propagating

At centres throughout the world producing rooted cacao cuttings, the number of leaves retained on each cutting may range from one to five. Otherwise most methods are similar in that the reduction of leaf size to reduce respiration is usual, as is a root-inducing hormone treatment, and placement in various types of units where

high humidities, low temperatures, and low light intensities prevail. Such units include enclosed "Trinidad-type" concrete propagators, glass-covered wooden boxes as used at Keravat, open beds under continuous sprays, beds under polythene sheeting and humidified glasshouses. More recently, polythene bags each containing a single cutting have been employed and the method shows some promise. A number of media, organic and inorganic, is used. Great variation exists from method to method in the frequency and intensity of watering, and rooting periods range from 18 days to 4½ weeks. Rooting efficiency varies considerably and success claimed ranges from 40 per cent. to 90 per cent.

Early Keravat Propagation

Harris (1953) described the method used at Keravat until 1951 and it is on his work that the present methods are based. His method involved the use of wooden propagating units (30 in. x 24 in. x 12 in. inside measurements) with cloth-covered glass lids. Well leached sawdust, approximately six inches in depth was used as a medium, and a commercial preparation, "Hormone 400" (a potassium indole butyrate/potassium naphthalene acetate mixture of unknown ratio or concentration), was used at 75 per cent. to 100 per cent. concentration. Overhead shade admitted approximately 25 per cent. of incident sunlight. Rooting period was 21 to 28 days, after which cuttings were potted out in bamboo tubes using a potting mixture composed of three parts black bush soil to one part composted sawdust, fortified with fertilizer. Hardening was carried out in Trinidad-type concrete propagators over a two-week period.

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The method, after promising initial results, proved disappointing, being characterized by heavy leaf breakdown and considerable rotting of the basal end of the stem within the propagating boxes, heavy losses during and after hardening, and frequent stagnation of growth after potting.

It must be remembered that Harris worked under primitive conditions, with extremely limited resources in an area recently an active war theatre. It is not surprising, therefore, that considerable modifications to his methods were made when more satisfactory facilities became available. None the less, Harris successfully initiated this facet of cacao improvement at Keravat and provided a sound foundation for later work.

Keravat Experiment Programme

When this work was commenced, it was obvious that emphasis in the first instance should be placed on reducing the very high post-potting losses, and on eliminating stagnation of potted cuttings, if any reasonable field establishment was to be obtained. This policy was followed rather than one of attempting to increase rooting percentages, and it paid large and early dividends. However, the experimental work is reported here according to the sequence of operations involved in striking cuttings, rather than in the chronological order in which the trials were conducted.

Material Nursery Establishment and Management

A limitation on large-scale production of rooted cuttings from a single tree is the number of flushes produced by that tree. Nutrition of the leaves is also of the utmost importance and mature trees, having borne crops heavily for a number of years prior to selection, are not well placed in this regard. Hence the first cuttings from a selected tree are planted in material nurseries. This is also a sound insurance against total loss of a potentially valuable clone, due to accident or disease destroying the mother tree.

Spacings vary a great deal from country to country, being as low as 4 ft. x 4 ft. but commonly are 6 ft. x 4 ft. Initial plantings at Keravat were at 9 ft. x 4 ft., but even with heavy cutting this spacing formed an impenetrable thicket by two to two and a half years

and spacings have since been gradually expanded to 12 ft. x 6 ft. Usually, first cuttings are ready to produce planting material at about 12 months of age.

Evans (1953) gave a well-balanced survey of factors within the cutting which greatly affect the success of propagation. The material nursery conditions which he investigated included soil fertility, physical conditions of the soil and light intensity. On the basis that the carbon-nitrogen ratio in the leaf was of prime importance, he recommended that in poor soils the light intensity be reduced to around 20 per cent. of natural light, increasing to a maximum of 50 per cent. with highly fertile soils.

Graham and Baseden (1956) draw attention to the inherently high nutrient level of the volcanic ash soils of the Gazelle Peninsula of New Britain. These workers emphasize, however, that maintenance of a high fertility level is entirely dependent upon maintaining a high level of organic matter in these soils. *Leucaena glauca* shade trees, together with leaf fall from cacao, provide sufficient organic matter for this purpose, and so the higher light intensities as recommended by Evans are approximated in the Keravat material nurseries.

The most important aspect of management of material nurseries is the timing of shade thinning. This is best done from the beginning to the middle of the wet season, when the weather is more overcast and duller. A good shade canopy is allowed to form in time for the onset of the dry season. Difficulties have been encountered after prolonged dry periods when rapid chlorosis of cuttings within four to six days of setting has been noticed. This is presumably due to the carbon-nitrogen ratio in the leaf being unduly high and may be corrected quickly by soil applications of urea.

Periodically it is necessary to prune the material nursery very heavily, replacing entirely the old branches with new growth. Soil dressings of nitrogen at the time of pruning are beneficial.

Collection of Cuttings

This is most convenient between 6 a.m. and 8 a.m., but several trials and long-term observations have indicated that the time of collection of cuttings has little, if any, effect on final success.



Plate I.—Leaf cuttings in propagating box at Keravat.

Cuttings are placed into sodden copra sacks immediately after removal from the tree, and are taken to the nursery where leaf area is reduced and hormone treatments are applied, prior to setting in the propagating boxes. Bags of cuttings are sometimes left until the afternoon before planting but provided that periodic applications of water are given no deleterious effects appear. Leaves must be kept moist at all times after removal from the tree.

Leaf and Stem Maturity

This is an aspect of cacao propagation which varies considerably from centre to centre, mainly because of varying conditions under which material nurseries are established, but also because of vastly differing rates of growth. The very marked effects which leaf maturity exerts on the degree of success attained has not always been appreciated.

Harris (1953) established a criterion for leaf maturity based on the texture of the laminal tissues. They were to be of the consistency of paper, sufficiently hard to rustle when crushed in the hand, but not so hard as to crack and split. Leaf colour was to be as deep a green as possible. Urquhart (1955), in reporting the

work of Evans, recommended that leaves be deep green in colour and that the dorsal surface of the stem be russeted, while the ventral surface should be a light green colour.

Castro (1952) obtained best results from material in full flush, the flush being removed before planting. Superiority, however, was dependent upon the use of an optimum hormone treatment (8,000 p.p.m. indole butyric acid), as similar cuttings without hormone gave poorest results. He concluded that the limiting factor in such material was a deficiency of natural hormones.

In material nurseries at Keravat, particularly in those nurseries under 18 months old, a problem exists wherein growth is frequently so rapid that one flush has not yet "matured" to either of the first two above standards before the apical bud develops further into a new "flush". This new flush can in extreme cases be up to 8 in. to 10 in. in length before russetting of the dorsal stem surface and a deep green leaf colour develops.

An objective and simple means of assessing maturity is necessary in New Guinea and it was decided that initial trials would be based

on the degree of development of the apical bud. Results of leaf maturity trials (Appendix I) showed that the incidence and vigor of rooting increase markedly in those cuttings where the bud had either commenced development or was actively growing provided that the apical leaf (or leaves) is removed. The extent of development of the apical bud has no appreciable effect on incidence of leaf breakdown, proportion of cuttings satisfactorily struck, or extent of root development. The results strongly suggested that leaf breakdown increases with increasing age of leaf. Theoretically one would predict larger functioning leaf area to be associated with increasing rooting vigour, which is contrary to the results obtained. Stem maturity trials (Appendix II) were conducted to determine the effects of age of the tissue at the base of the cuttings. It was found that root primordia were initiated earlier in young tissues (Fig. A3). The vigour of rooting appeared to be much greater in younger tissues, but this may not have been statistically significant. Younger tissue showed greater development of basal callus in the early stages, but this did not inhibit early root development.

Apparently leaves fare better when the older stem tissue is retained (Fig. A5), but this may be due to the longer stem used, rather than its age.

Lamina Size

Establishment of a minimal size to which leaves may be reduced has some bearing on the final cost per cutting with most forms of cacao propagation. This is because it dictates the number of cuttings which may be planted in any given area of propagating space. Theoretically, the extent of leaf reduction will also affect the respiration/photosynthetic balance.

Results of an experiment to determine the effect of various leaf areas (Appendix III) showed that best results were obtained when the leaves were cut at from three to five inches along the midrib.

Planting in the Boxes

Cuttings are inserted between $2\frac{1}{2}$ inches and $4\frac{1}{2}$ inches into the rooting medium, the determining factor being the length of the cutting. Spacing varies from 30 to 40 cuttings per five square feet, 32 being most common. No comparative trials on spacing within the units have been carried out.

Rooting of Cuttings

A number of experiments was conducted to determine the most satisfactory means of rooting cuttings. These included a series of hormone trials to assess the relative efficiency of hormone-type rooting stimulants. Results (Appendix IV) of a trial to establish the optimum concentration of Hormone 400 (H400) using the quick-dip method showed that the number of cuttings rooted increased markedly with concentrations of hormone up to 75 per cent., but that they fell off when the hormone concentration exceeded that figure. Both leaf breakdown and basal stem rotting increased directly with the hormone concentration, whereas the formation of basal callus decreased.

Root production was most satisfactory in the 75 per cent. treatment and notwithstanding the defects of high leaf breakdown and basal rotting this was regarded as the best concentration to use.

An experiment to obtain by a "dilute method", stimulation comparable with that achieved with the 75 per cent. concentration of H400 showed that all hormone treatments—whether "concentrated" or "dilute"—increased both number of cuttings struck and the total root weights when compared with a water control. (Appendix V.) Of the treatments used, that using a 2 per cent. H400 solution and soaking for three hours gave results comparable (with regard to rooting percentage and vigour) with the 75 per cent. dip, and the level of leaf breakdown and basal rotting were appreciably lower although still at an unsatisfactory level.

Both these trials showed that the stimulative and phytotoxic ranges of H400 overlapped to an unfortunate degree.

Trials with naphthalene acetic acid (N.A.A.) showed similar trends for rotting, leaf-breakdown and callus formation as did trials with H400. However, a similar trial concerned with a 2,000 to 10,000 p.p.m. range of β indole butyric acid (I.B.A.) in 50 per cent. alcohol indicated that I.B.A. gave satisfactory results in comparison with H400. The optimum range of 6,000 to 8,000 p.p.m. gave a higher percentage strike with a strong suggestion of increased vigour of rooting, and with a markedly lower level of leaf breakdown and basal rotting than H400. A further trial to confirm these results

was also used to see if there were any significant differences in the effects of 6,000, 7,000 and 8,000 p.p.m. of I.B.A.

It was determined (Appendix VI) that a significantly greater number of cuttings struck after the 7,000 and 8,000 p.p.m. I.B.A. treatment than after the H400 treatments. Leaf breakdown and basal rotting in the I.B.A. treatments were comparable with the levels obtained when no hormone was used and were far below the levels for the H400 treatment.

Evans (1953) had found a mixture of I.B.A. and N.A.A. to be superior to I.B.A. alone; and trials with different mixtures of I.B.A. and N.A.A. were conducted at Keravat. However, the use of N.A.A. and I.B.A. to give a total hormone concentration of 8,000 p.p.m. significantly reduced both the incidence and vigour of rooting. (Appendix VII.) Because of these results, I.B.A. at 8,000 p.p.m. is now used exclusively at Keravat.

Leaf Breakdown, Basal Rot and Basal Callus

Evans (1953) considered the air-water relations of the medium to be the most critical of the external factors involved in the successful rooting of cacao cuttings. He demonstrated that basal rot was attributable to a high water-to-air ratio in the pore spaces of the medium, while a low water-to-air ratio resulted in the excessive development of basal callus. Where the water was slightly excessive, but not to such a degree as to cause rotting, he noted a proliferation of callus rods of undifferentiated tissue produced from the phellogen and growing through the lenticels. These were first white, then suberized and turned brown.

It is suggested that an important direct effect of any of the stimulants used is to heighten the sensitivity of the cutting to excessive water in the medium. This could possibly be due to increased oxygen requirements at the site of root development.



Plate II.—Bases of cuttings after 28 days in the nursery.

(The cuttings show effects of hormone concentration on root development, basal rot and basal callus. Cuttings are paired, showing dorsal side on left and ventral on right. Concentrations (left to right) —0 (water control); 4,000; 8,000; and 12 000 p.p.m. I.B.A.)

Note optimum root development at 8,000 p.p.m.; decrease of basal callus and increase of callus rods on stem as hormone concentration increases; and basal rot at 12,000 p.p.m. which has killed any roots developed.



Plate III.—Enlarged view of base of rooted cutting, treated with 8,000 p.p.m. I.B.A.
(Whitish basal callus may be seen between the wood and the bark.)

The negative correlations noted in the dilute method hormone trial (Appendix V) between basal rotting and basal callus, together with the decreasing callus production with increasing hormone concentration, supports this hypothesis. There is also the observation that in every case where a "no hormone" control has been used, the cuttings have developed very few callus rods; the incidence of these rods appears to increase directly with hormone concentration. This occurs under air-water relationship conditions which are quite standardized. Unfortunately, due to the difficulties of devising a suitable objective measurement for this feature, no numerical data have been collected, but the photographic evidence in Plate II aptly demonstrates the point.

Basal callus pads produced on the control cuttings are typically large and hard. The incidence and total quantity of callus produced

appears to lessen as hormone concentration increases, so that with I.B.A. at 8,000 p.p.m. the average cutting appears, as in Plate III to have a ring of callus tissue formed between the bark and wood of the stem. Callus tissue may or may not be present over the cut end of the stem at this concentration.

Extreme basal callus formation has frequently been regarded with disfavour, on the ground that it retards root initiation and development. This view is probably correct. However, due to the negative correlation between the incidence of rotting and callus, it is considered that, provided callus development is not excessive, it may be regarded as a sound insurance against rotting. A considerable degree of tolerance by the cutting to fairly heavy callus production has been noted. Callus and rot on a single cutting has been rarely noted.

Leaf breakdown has been observed in many instances to increase directly with hormone concentration. Apart from possible direct toxicity, this indicates an increase in general metabolic rates and stresses the need for material to be in an optimum condition when removed from material nurseries, together with the need for optimum light intensity over the propagating units. Under normal Keravat conditions using I.B.A., leaf breakdown, which is not always present, is restricted to a faint background mottling and presents no serious problems.

Alvim and Duarte (1954) incorporated fungicides with the hormone treatment with success, as did Desrosiers and von Buchwald (1955) in combating *Diplodia theobromae* and *Fusarium* spp. which caused excessive leaf breakdown and moist basal stem rotting. Pathologists at Keravat have never found causal organisms for basal rotting but even so a trial was conducted to examine whether "Cuprox", a commercial preparation with copper oxy-chloride as the active constituent, had any effect on rooting. Results (Appendix VIII) showed that Cuprox had no ameliorating effects on either leaf breakdown or basal stem rotting but strongly suggested that they increased with increasing hormone concentration. Thus, it appears that rotting at Keravat has been physiological. There have been, however, two outbreaks of leaf breakdown caused by fungi. One very small outbreak of leaf breakdown in 1955, due to a tentatively identified *Septocylindrium* sp., was controlled by stringent nursery hygiene methods. A more serious outbreak in July, 1959, was controlled by spraying a very strong solution of Cuprox on all units and into the rooting medium. The source of these two infections is still unknown.

Hardening of Rooted Cuttings

Evans (1953) emphasized that successful hardening depends upon a realization by the nurseryman that two phases are involved in the process. They are :—

- (i) A development period where root growth is encouraged so that the root system is capable of supplying the water requirements of the plant ; and
- (ii) A period wherein the plant is acclimatized to lower humidities and higher temperatures than those prevailing in the propagating units.

The method of Harris (1953), which was similar to methods in common use overseas, left much to be desired, and losses during the hardening period were frequently excessive. It consisted of lifting the cuttings at 21 days and potting those that were satisfactorily struck, the remainder being returned for a further seven days before final potting was carried out. The potted cuttings were placed in Trinidad-type propagators with glass lids. The glass lids were closed for the first two days, and then raised to an inch and a half for the next three days with one watering a day. After this, the lids were raised to three inches for another nine days, with only one watering in this time.

An early introduction of *in situ* hardening (since superseded by an improved method described below) was made without any experimental evidence to justify its introduction and resulted in markedly lower losses during hardening than those normal to hardening in the I.C.T.A.-type bins.

In situ hardening

This usually commenced on the 23rd to 24th day after setting, and consisted of gradually raising the glass covers of the propagating box for seven to nine days, after which the glass was removed for one to three days before potting. Later, it was deemed necessary to inquire further into the optimum commencement date for *in situ* hardening, and a comparison with hardening in I.C.T.A. bins was included in the trial. (Appendix IX.)

In situ hardening proved to be a highly significant improvement over hardening in I.C.T.A. bins. Differences between dates of commencement of *in situ* hardening failed to attain significance, but this was ascribed to the cool, rainy weather which prevailed at the time the trial was run.

Although *in situ* hardening gave satisfactory results, the great amount of supervision necessary, and the unduly large amount of labour involved, render this method unsuitable when large numbers of propagating boxes are in use.

Present "hardening" method

For the method now successfully in use at Keravat, "hardening" is scarcely an appropriate term. Cuttings are lifted after 27 to 30 days and are then potted and placed on a concrete floor under a lath house admitting 50 per cent.

of incident sunlight when the sun is overhead. Above the floor is a spray installation. The spray system is powered by a 7.5 h.p. electric motor with a centrifugal pump capable of working 100 spray nozzles at a pressure of 60 lb./square inch. The spray nozzles are Rega No. 1 model with an 0.031-inch orifice and at the above pressure deliver approximately $7\frac{1}{2}$ gallons per hour per jet; the spacing of six feet by seven feet allows a fall of about 0.3 in. per hour of equivalent rainfall. Bore water of excellent quality, free from injurious salts, is available in a reasonable supply.

Spray irrigation is applied fairly constantly from 8 a.m. to 3.30 p.m. for the first four to six days, after which it is cut abruptly to one to three applications a day of about 10 to 20 minutes' duration for a further two and a half to three weeks.

Extremely rapid bud development is made under these conditions. Experiments involving a range of light intensities over newly-basketed cuttings, though not conclusive, indicated that

higher light intensities initiate earlier bud burst than do lower intensities, but result in slightly chlorotic and slightly dwarfed leaves if maintained for sustained periods. However, for the short period required of three to three and a half weeks, these leaf symptoms are not unduly marked, while the effect of early bud development is noticeable. It is highly probable that there is also a quicker build-up of carbohydrates under these high light conditions. This would be beneficial in cuttings which have, of necessity, been for a fairly long period under extremely low light intensities (approximately 12 per cent. inside the propagating boxes).

After removal from the spray floor, cuttings are placed under *L. glauca* shade, admitting an evenly-diffused 25 to 35 per cent. of incident sunlight. They remain there for periods ranging from six to eight weeks prior to planting in the field, although some slower clones require a longer period. The only attention given is occasional watering in dry weather, weeding and snail baiting.



Plate IV.—Potted cuttings hardening under *Leucaena* shade after removal from nursery.

Thus, generally speaking, the cuttings are retained in the nursery lath house for about seven weeks, and then go under natural shade for another seven weeks or so before field establishment. The economy of retaining the cuttings under an expensive spray system for a period of three to three and a half weeks may be queried, but it must be remembered that a rooted and potted cutting is quite expensive to produce, and once cuttings reach this stage any losses sustained are of far greater importance than losses

in propagating units. The use of natural shade after this period, in place of artificial shade houses as used overseas, more than favourably counterbalances this expense.

Losses in potted cuttings being held under natural shade are rare, and due to physical damage or occasional fungal attack. The *L. glauca* evidently breaks up direct raindrop action, as damage to developing leaves is of no consequence.



Plate V.—Well-rooted cuttings at the correct stage for potting.



Plate VI.—Potting the rooted cutting.

Potting

This is quite simply carried out, and providing a little care is exercised, presents no problems. Cuttings are lifted from the rooting boxes and shaken, or preferably tapped with the finger, in order to remove excess sawdust, though some is left adhering (Plate V). They are then carried to the potting area, where supplies of potting soil and baskets are ready. It must be borne in mind, when handling cuttings at this stage, that their roots are very brittle and will not take rough handling.

An inch or so only of potting soil is placed in the bottom of the basket, and the cutting held suspended with roots hanging while soil is dribbled into the baskets with the free hand. (Plate VI). Care is taken to see that roots are not distorted and that they are evenly distributed in the soil. Only very gentle firming

of the soil is carried out by hand, the main firming of the soil around the roots resulting from the action of water under the continuous spray system where the cuttings are next placed. (Plate VII).

The potting is carried out in the nursery shade house and direct sunlight falling on bare roots is avoided.

A trial was laid down to test an alternative potting soil to that employed by Harris and to determine whether fertilizer applications in the potting soil were effective (see Appendix X).

Soils used included a black bush soil consisting of volcanic sand from which a great deal of the finer particles have been removed by water and a "mimosa mulch". This "mulch" is collected by slashing and rolling back masses of *Mimosa invisa* and raking up accumulated mulch (two inches to four inches in depth) plus



Plate VII.—Potted cuttings hardening on the nursery spray floor.

(In the background is a trolley used for moving the potted cuttings.)

approximately half an inch of topsoil. It is then sieved through a half-inch wire mesh before use. The pH is approximately 5.6.

It was evident from the results obtained that the mimosa mulch resulted in markedly improved growth rates, and caused the earlier commencement of growth. At five weeks after potting,

the superiority of mimosa mulch was due entirely to an earlier growth initiation and a breaking of the stagnation common to the black soil treatments. The numbers of new leaves per flushing cutting varied to no significant degree between any two treatments, differences being confined to the proportion of cuttings flushing. Nine

weeks after potting, however, it was clear that the treatment differences were mainly attributable to different actual rates of growth, the black soil treatments producing approximately three leaves per flushing cutting and the mimosa mulch more than five leaves per flushing cutting. Such differences between soil types became further accentuated with time (see Figure 1). A

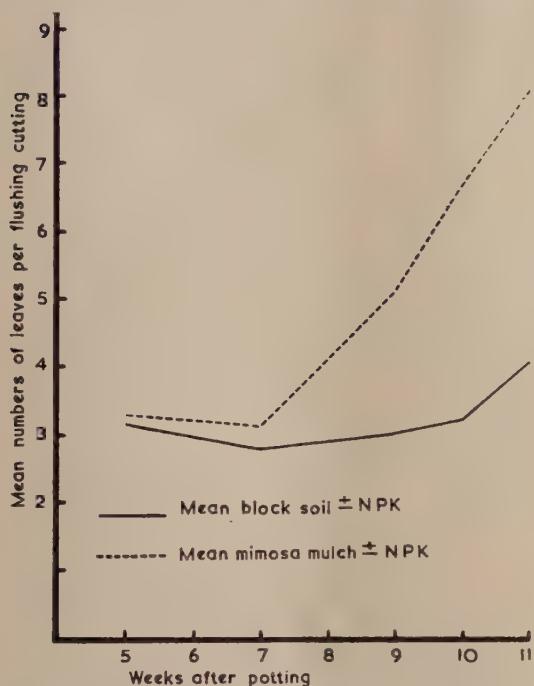


Fig. 1.—Potting soil trial—effects of different types of potting soil on rate of cutting growth.

significant response to the fertilizer treatment used was obtained only with the volcanic sand and the effects of this disappeared between seven and nine weeks after potting. The unfertilized black soil produced a significantly higher death rate at 14 weeks after potting.

The type of measurements taken, however, although satisfactorily demonstrating that significant differences existed, did not reflect the differences of greatest practical value: i.e., differences in apparent health and size of new foliage produced, in which the mimosa mulch treatments were far ahead of the black soil treatments. At the time of completion of this experiment, 14 weeks after potting, the cuttings growing in mimosa mulch were ready for field planting, whereas those in the black soil were

stunted and deaths were occurring with increased frequency. Since this experiment, mimosa mulch has been adopted as the standard potting medium and calculations over large numbers of cuttings have shown that the post-potting losses up to the time of field establishment have been lowered from something in excess of 50 per cent. to between one and a half and two per cent.

Later, a similar mulch collected from under established *Pueraria phaseoloides* proved as satisfactory as the Mimosa mulch, although rather more difficult to sieve. It is also evident that mimosa needs to be established for at least 18 months before providing a really first-class mulch in suitable quantities. Accurate assessments of the amount of mulch collected per acre have never been made, but the yield is very substantial.

Pot types

A further trial was set up to determine the suitability of bamboo tubes as pots for cacao cuttings and to compare them with the type of basket used overseas. This trial was also to check the results of the "potting soil" trial and to determine any interactions between pot types and potting-soil types.

Results (Appendix XI) showed that, regardless of pot type, the black soil was inferior to the mimosa mulch (thus confirming the results of the previous trial). Considering pot type alone, there is no appreciable difference. However, there is a very marked interaction between pot type and soil type. Baskets with mimosa mulch were superior to all other treatments, and baskets with black soil were inferior to all other treatments. The discrepancy between soil types was clearly lessened when bamboo pots, rather than baskets, were used.

It is clear, therefore, that a consideration of pot type alone is insufficient when more than one potting medium is under test. It is possible that water relations may be responsible, at least in part, for this interaction.

The use of baskets as a pot type with mimosa mulch as a potting medium was adopted for all clonal cacao at Keravat after the completion of this trial, and has given highly-satisfactory results.

Other Potting Trials

A fertilizer trial was conducted involving NPK separately and in all combinations over a range equivalent to two hundredweight to 12

tons/acre added to mimosa mulch further to enhance post-potting growth. Completely negative results were obtained indicating that a highly satisfactory nutrient level was already present.

Additional trials carried out from time to time using Urea sprays, commercially prepared "complete" foliar nutrient sprays and several post-potting hormone treatments all yielded negative results, and it is evident that little scope exists for further growth improvements in the post-potting period.

Transport of Rooted Cuttings Outside the Gazelle Peninsula

Because of the Giant Snail (*Achatina fulica*) infestation in the Gazelle Peninsula, and also because of the high cost of shipping bulky material, where possible bare-root transport of cuttings by air to centres outside of snail areas has been conducted.

Cuttings are carefully removed from the potting soil and examined for snail eggs or young. They are then placed with the roots in well-leached sawdust identical to the striking medium, wrapped in brown packing paper, placed in polythene bags .002 in. in thickness, with about one-third of a pint of water and tightly sealed. Packing usually takes place during the night preceding the aircraft's departure.

In an initial consignment to the Lae area, almost 100 per cent. mortality was encountered. Cuttings were quite satisfactory for three days after transplanting, but after this an extremely rapid chlorosis without loss of turgor was evident. This was followed by loss of turgor after 18 to 30 hours with subsequent necrosis and death of the cuttings.

Investigations carried out at Keravat revealed :—

1. Washing of the roots to remove soil was not injurious.
2. No benefits were obtained by spraying with foliar nutrients either before or after transport was effected.
3. Cuttings with soft developing flushes were more susceptible to damage than completely hardened cuttings.
4. Percentage successful establishment diminished as the size of the cuttings increased.
5. There was a possibility of overcrowding in the bags, causing a build-up of CO₂. Six cuttings (remaining in the baskets)

each with only hardened leaves were individually enclosed in polythene bags. Six similar cuttings were enclosed in polythene bags containing a CO₂ saturated atmosphere. A similar series of treatments was applied to cuttings each carrying a soft young flush. Treatment duration was 24 hours. Chlorosis symptoms appeared within 24 hours on five out of six cuttings in the young flush x CO₂ treatment. This was accompanied by some shrivelling of the young flushes. Systemic symptoms identical to those encountered at Lae occurred on two of these cuttings after 48 hours. These two cuttings died after six days. No symptoms appeared on other treatments.

6. It was concluded that the basic cause of the failure in this Lae shipment lay in the highly alkaline nature of the potting soil supplied (pH 8.46).

In the light of the above investigations, the following precautions are now taken with all consignments forwarded from Keravat :—

1. Proposed potting media are tested at Keravat before shipment.
2. Number of cuttings per bag is limited.
3. Only small cuttings with one or sometimes two hardened flushes are used.
4. Packing is carried out in humid conditions.
5. A minimum of delay between packing and repotting is arranged.

Attention to these details has given in most instances 100 per cent. successful establishment, heaviest losses to date for centres other than the Lae consignment being 10 per cent. in one small batch. Eighteen hours has been the maximum time interval between commencement of packing and completion or repotting with all except one consignment of 300 cuttings which was made by ship. The delay here was 38 hours and 97 per cent. were successfully established. Maximum permissible delay has not yet been assessed.

Polythene Bag Technique of Striking Cutting

Nichols (1958) devised a method of rooting cuttings individually in plastic bags, at approximately one-quarter the cost of normal methods and in such a way that the rooted cuttings were planted directly into the field at three and a half weeks after setting. The cuttings are pre-

pared in the usual manner, and the basal ends placed in a handful of moist, well-leached sawdust, which is then wrapped in coconut fibre and fastened with a rubber band. This is next placed in a plastic bag with 150 ml. of water, sealed and suspended under about 7 to 12 per cent. of natural light. The possibilities of such a method in this Territory are almost unlimited, where the costs of transport over long distances are high, where bare root transport is necessary when introducing cacao from the Gazelle Peninsula to snail-free areas and where it is obvious that we are seeking a method sufficiently simple for the use of private growers.

Preliminary experiments have been most encouraging with this method, but final assessment of the method will take at least 12 months more, as it remains to be seen whether the coconut fibre unduly restricts root development after planting in the field, and if this does happen, whether it is only a temporary setback. One drawback to the method exists in the greater amount of time needed in preparation of the cuttings, but this is compensated for by having no periodical waterings, by making greater use of available shade house space, and by not having to maintain the cuttings in the nursery until field establishment.

Future Work on Cacao Propagation

Results on a reasonably large scale of clones tentatively approved for release have, over the past few months, averaged a little more than 80 per cent. successfully struck, potted and hardened. It is considered, therefore, that little scope remains for further improvements in treatments applied to the cutting itself, such as further hormone stimulation, better leaf maturity standards, etc.

Future work will be concentrated on the economic rather than technical side of propagation: The non-durable nature of the wooden boxes and breakages of glass covers make the type of unit used to date rather expensive, and future work is to be concentrated on new types of structures, built from more-permanent materials, with wider use of polythene-type plastics in place of glass. Open spray methods of propagation are to be attempted.

Present costs of production are around 23 to 24 pence per cutting (to field establishment) and it is hoped to be able to reduce this by a very appreciable percentage.

Summary of Present Methods

In order to draw together the results of the experimental work described, the methods currently used to establish cacao cuttings will be briefly outlined.

Cutting material is preferably obtained from material nurseries, where clones are grown under *Leucaena glauca* shade, admitting approximately 50 per cent. of normal light. The nurseries are pruned periodically and fertilized with nitrogen.

Cuttings are taken from the youngest mature flush, at a stage when leaves are dark green and the dorsal surface of the stem is russeted. The apical bud will have swollen and may have grown to as much as eight inches in length. This cutting material is carried to the nursery in wet copra sacks. There, according to the degree of development of the bud, either the bud alone or the bud plus one or two apical leaves are removed and three mature leaves retained, the stem being cut three to four inches below the lowest leaf. The leaves remaining are reduced by cutting the lamina back to three and a half inches to four and a half inches in length.

The base of the cutting is dipped quickly into a solution of 8,000 p.p.m. β indole butyric acid in 50 per cent. alcohol, and inserted in the propagating medium to about the base of the oldest leaf retained. The rooting medium consists of about six inches depth of well-leached sawdust. The propagating box used is wooden, 30 inches by 24 inches by 12 inches inside measurements, with cloth-covered glass lid. Cuttings remain in the box about 28 days, during which time they are watered about three times daily with a knapsack spray.

They are then taken out, tapped lightly to remove excess sawdust, and carefully potted in baskets with mimosa mulch. The baskets are placed under 50 per cent. light with fairly constant mist spray for four to six days, thereafter occasional spraying for two and a half to three weeks. They are then transferred to *Leucaena* shade (25 per cent. to 35 per cent. light) until ready of planting usually in six to eight weeks.

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APPENDICES

Note to Appendices

EXPERIMENTAL METHODS.—

Unless otherwise stated, all experiments described were of randomized-block designs. Some limited use of "pilot" trials was made, and several large-scale, split plot designs were used. In the randomized block designs individual boxes represented a plot, with contiguous boxes grouped into blocks. "Difficult" clones were used wherever possible in rooting trials, the aim being to establish trends over a wide range of treatment levels. Such trends may be masked by the clonal effect should really vigorous rooting clones be used, since such clones often root well regardless of the treatment applied. A subsidiary, though important, reason for the use of "difficult" clones in rooting trials is that in the breeding programme at Keravat (Bridgland, 1959) numbers of cuttings are required from many inbred and weak trees for planting in the production of "hybrid" seed. Some of these clones make extremely poor growth and are very difficult to establish successfully.

All cuttings used were three-leaved and unless otherwise stated had the leaves reduced to three and one-half inches to four inches in length.

Appendix I.

Leaf Maturity Trial.

—	Functioning Leaves.	Cuttings Struck.	Cuttings Satisfactorily Struck.	Root Weight per plot (mgm).
Treatment A	45.4	14.1	8.3	419
B	38.4	10.6	4.6	170
C	33.5	11.8	6.9	324
D	31.8	14.9	12.4	975
E	28.6	15.3	12.6	1,059
Standard Error	± 6.46	± 2.19	± 2.00	± 195.7

Notes.—

1. Eight replicates of 18 cuttings per plot. Measurements were made 27 days after setting.
2. A "functioning leaf" is defined as one which may reasonably be expected not to absciss before a flush has developed and matured on the basketed cutting (i.e., leaf does not break down).
3. Three classes of cuttings were collected—

Class I.—The apical bud still dormant, the leaves were medium green, and in most the dorsal surface of the stem remained green, although first signs of russetting were present.

Class II.—The apical bud was between bud swell and an inch and a half growth of new flush. Leaves were deeper green than Class I, and russeting was general. Ventral surface of the stem remained green.

Class III.—The apical bud was between four inches and eight inches long. Leaves were deep green as was the ventral surface of the stem.

Treatments were.—

A—Class I cutting—apical, second and third leaves retained.

B—Class II cutting—apical, second and third mature leaves retained, the developing flush nipped off with fingers.

C—Class III cutting—apical, second and third mature leaves retained, the developing flush nipped off with fingers.

D—Class II cutting—apical leaf removed—second, third and fourth mature leaves retained.

E—Class III cutting—apical and second leaves removed, third, fourth and fifth mature leaves retained.

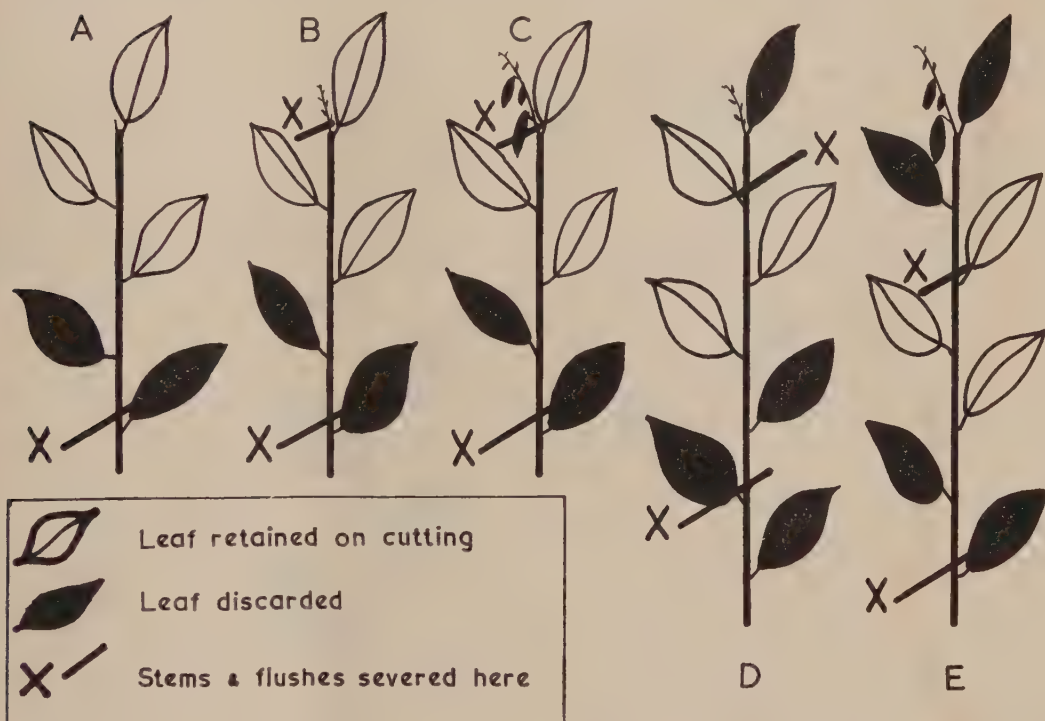


Fig. A1.—Diagram showing treatments used in leaf maturity trial.

DISCUSSION.—

The differences between treatments B and D, and between C and E are probably due to an increase in an inhibiting substance which is produced either in the apical leaves or at the base of the apical bud at the time of bud swell and subsequently while the developing flush is rapidly growing.

Since the differences in treatment between B and C, and D and E involve the removal of tissues, it is much more likely that the superiority of the latter treatments is due to the removal of an inhibitor rather than to any function of natural stimulants. An additional support for this theory lies in the strong inference of depressed rooting after discernable bud development has commenced—viz., difference A—B, A—C. Subsequent observations have indicated a probable clonal response to these types of treatment which can be very strong. An alternative explanation could be one of differing physiological age of the stem tissues at the site of the basal cut, whereby the older tissues may be able to differentiate primordial roots more rapidly than younger tissues.

Appendix II

Stem Maturity Trial

The aim of this trial was to inquire into the effects exerted by the age of the tissues at the base of the cutting.

Two treatments were used, all material conforming to the standards of either Classes II and III as described in the previous trial, which were found to be not significantly different.

Treatment A—Apical, second and third leaves retained; fourth leaf removed and basal cut made above the fifth node. This corresponded to treatments B and C in the previous trial.

Treatment B—Apical, second and third leaves retained; fourth, fifth and sixth leaves discarded with the basal cut made above the seventh node. This combined the leaves of treatments B and C with the basal cut of treatment E in the previous trial (Figure A2).

Two clones were involved and results represent the yield figures for the combined clones as no differences in trends between clones were noted. Four samples of four cuttings and eight samples of three cuttings (total of 40 cuttings) were taken on each sampling day, the days being the 16th, 20th and 22nd days after setting in the propagating boxes. No statistical analyses were made on the data collected, but results can clearly be seen from Figures A3, A4, A5 and A6.

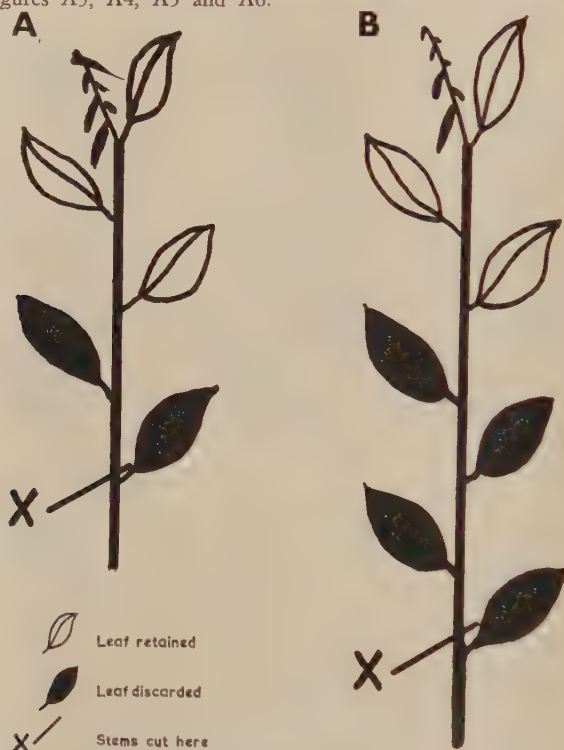


Fig. A2.—Diagram showing treatments in stem maturity trial.

The total number rooted did not vary greatly at the time of the final sampling, but earlier initiation of root primordia in young tissues is evident (Figure A3). The vigor of rooting appears to be much greater in younger tissues, but this difference is only really pronounced after 20 days from setting, and may have been due to sampling errors (Figure A4). From a comparison of Figures A4 and A5 it is fairly clear that early callus formation does not inhibit early root development. Leaves appear to fare better when the older stem tissue is retained (Figure A6) although this could easily be due to the greater length of period is longer than 22 days as, up to the 20th day, roots were still just appearing through the cortical tissues of many cuttings and the rate of increase in vigour (Figure A4) was increasing markedly.

It is apparent that the second hypothesis mentioned in the previous trial, namely, that older stem tissues may be able to differentiate primordial roots more readily than younger tissues, is not tenable. In fact, the reverse is the case when comparable leaves are retained on the cutting.

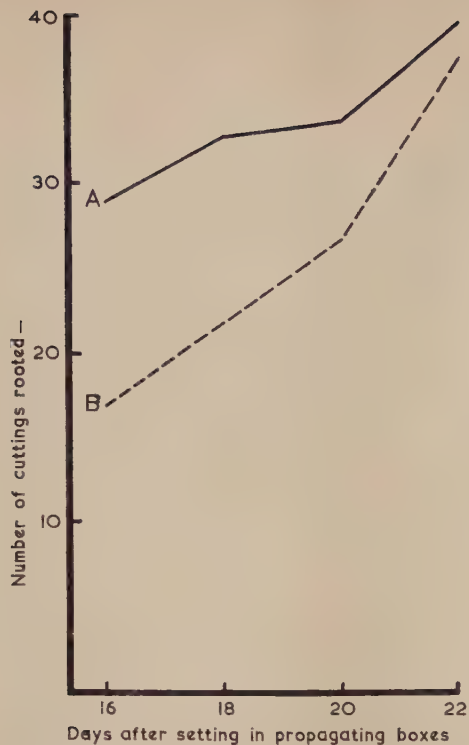


Fig. A3.—Stem maturity trial—effect of stem maturity on time taken for root development.*

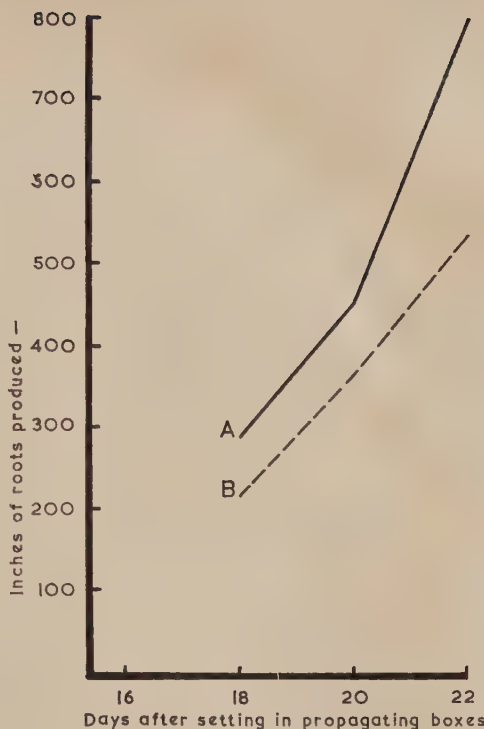


Fig. A4.—Stem maturity trial—effect of stem maturity on vigour or rooting.*

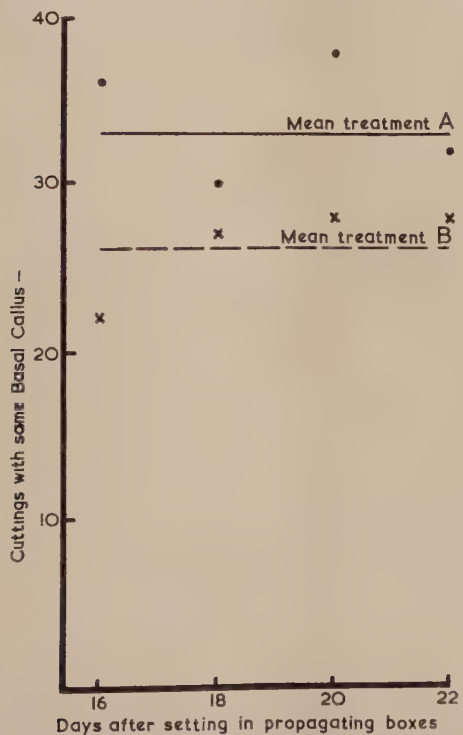


Fig. A5.—Stem maturity trial—effect of stem maturity on development of basal callus.*

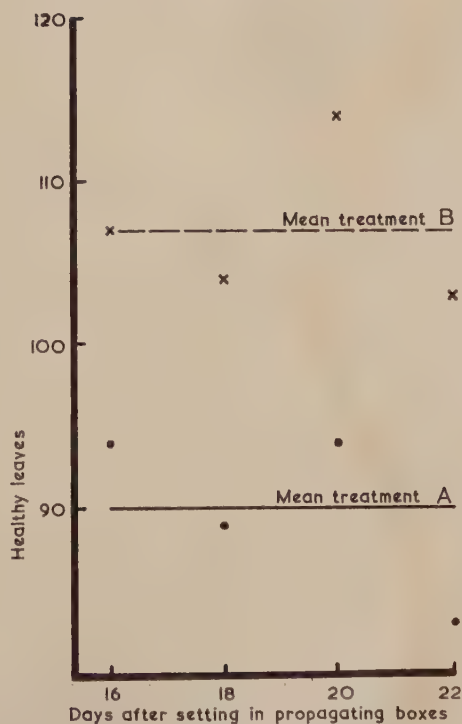


Fig. A6.—Stem maturity trial—effect of stem maturity on leaf breakdown.*

* Forty cuttings sampled on each date.

Appendix III.
Optimum Leaf Size Trial

—	Cuttings rooted.	Dry Weight of roots per plot (mgm).	Leaf Breakdown.
Lamina cut 1 in. along midrib	7.7	66	20.5
Lamina cut 2 in. along midrib	17.5	485	16.6
Lamina cut 3 in. along midrib	15.0	410	9.2
Lamina cut 4 in. along midrib	16.0	593	8.6
Lamina cut 5 in. along midrib	17.2	492	7.7
Lamina cut 6 in. along midrib	14.0	256	8.4
Standard Error	± 1.87	± 112.31	± 1.84

Notes.—

1. Eight replicates with 21 cuttings per plot. Measurements were taken 21 days after setting.
2. All treatments received 8,000 p.p.m. I.B.A. hormone treatment.

DISCUSSION.—

A correlation coefficient $r = 0.996$, $P < .01$ for laminal length and area was calculated showing length to be a satisfactory index of area.

The one-inch treatment, with low percentage strike and root weights, together with high leaf breakdown was obviously below the minimum satisfactory leaf size. At the other end of the scale the six-inch leaves appeared to have a markedly depressed root weight with a strong suggestion of reduced rooting percentage, although the difference is not significant. The two-inch treatment was unsatisfactory in regard to leaf breakdown and it would appear that the optimum length lies between three inches and five inches.

One striking feature of the trial not apparent from the data, was the similarity observed between the six-inch treatment, and to a lesser extent the five-inch treatment, and "control" cuttings in hormone trials. Leaves in these treatments remained a very deep green colour, basal rotting was entirely absent, basal callus was quite heavy and callus rod production negligible. The reverse situation was evident in the one-inch and two-inch treatments.

Appendix IV.

Trial to determine optimum concentration of Hormone 400.

—	CONCENTRATION OF H400						STANDARD ERROR
	100%	75%	50%	25%	5%	0%	
Total Struck	15.0	20.6	18.9	20.6	18.6	13.1	± 1.66
Dry Weight Roots/plot mgs.	500	1016	554	641	252	100	± 108.82
Leaf Breakdown	32.6	26.5	18.9	12.1	15.3	7.8	± 3.92
Basal Stem Rot	21.9	16.2	9.6	7.3	4.1	1.0	± 1.48
Basal Callus	0.0	0.6	1.1	3.4	3.8	11.6	± 1.18

Note.—

Eight replicates of 24 cuttings per plot. Recordings were made 21 days after setting.

DISCUSSION.—

Both leaf breakdown and basal stem rotting increased directly with hormone concentration, whereas the formation of basal callus increased inversely with hormone concentration. A positive correlation $r = 0.974$, $P = < .001$ was noted between leaf breakdown and basal stem rotting; a negative correlation coefficient $r = -0.796$ for stem rotting and basal callus just failed to attain statistical significance at the 5 per cent. level. Root production was most satisfactory in the 75 per cent. treatment.

Appendix V.

"Dilute method" trial using Hormone 400.

—	Number Struck.	Dry Wt. Roots/plot (mgm).	Leaf Breakdown.	Basal Rot.	Basal Callus.
75 per cent. H400 concentrated dip	9.9	285	18.9	10.4	0.9
5 per cent. H400 with 2-hour soaking	10.4	250	16.3	11.9	0.6
5 per cent. H400 with 1-hour soaking	11.8	510	16.8	9.1	2.1
0.5 per cent H400 with 6-hour soaking	11.0	194	8.9	1.3	10.1
2 per cent H400 with 1-hour soaking	11.6	241	9.8	4.5	6.8
2 per cent. H400 with 3-hour soaking	11.5	355	11.6	5.9	4.8
Water control	6.9	56	3.4	1.3	12.6
Standard Error	± 1.10	± 68.70	± 2.31	± 1.12	± 0.83

Notes.—

Eight replicates of 14 cuttings per plot. Measurements were made 21 days after setting.

DISCUSSION.—

Correlation coefficients $r = 0.922$, $P < .01$ between leaf breakdown and basal rotting, and $r = -0.973$, $P < .001$ between basal rotting and basal callus were calculated.

Appendix VI.

I.B.A. Concentration Trial.

—	Cuttings Struck.	Root Wt. per plot (mgm).	Leaf Breakdown.	Basal Rot.	Basal Callus.
Water control	3.8	19	8.3	0.8	15.3
75 per cent. H400	11.1	397	30.9	17.5	0.2
6,000 p.p.m. I.B.A.	13.0	386	7.8	0.4	12.4
7,000 p.p.m. I.B.A.	14.3	429	9.2	1.2	11.8
8,000 p.p.m. I.B.A.	14.1	533	8.8	0.0	10.9
Standard Error	± 1.14	± 81.58	± 2.04	± 0.45	± 1.39

Notes.—

1. Twelve replicates of 18 cuttings per plot. Measurements were made 21 days after setting.

2. The differences in root weights between hormone treatments were mainly attributable to the differences in the number of cuttings struck, rather than to differences in vigour of rooting

Appendix VII.

I.B.A.—N.A.A. Mixture Trial.

—	Cuttings Satisfactorily Struck.	Root Weight per plot (mgm).
8,000 p.p.m. total hormone comprised of—		
I.B.A. alone	5.7	590
2 parts I.B.A. : 1 part N.A.A.	4.2	271
1 part I.B.A. : 1 part N.A.A.	2.2	108
Standard Error	± 0.55	± 75.5

Notes.—

1. Twelve replicates of eight cuttings per plot. Measurements were made 28 days after setting.

2. No attempt was made to measure the activity of the N.A.A. which may have been low thus causing the divergence from the results of Evans (1953).

Appendix VIII. Cuprox Trial.

	NO CUPROX				1 OZ. CUPROX/C. FT. MEDIUM				2 OZ. CUPROX/C. FT. MEDIUM				—
—	Water Control	25% H400	75% H400	Total	Water Control	25% H400	75% H400	Total	Water Control	25% H400	75% H400	Total	Standard. Error
Leaf breakdown	3.4	14.0	22.7	40.1	5.4	14.4	22.0	41.8	5.5	12.5	25.4	43.4	± 2.69
Basal Rot Incidence	0.9	5.9	11.0	16.8	0.6	6.6	11.4	18.6	1.1	5.6	11.7	18.4	± 0.92
Basal Callus	9.5	4.4	0.2	14.1	9.5	3.1	0.5	13.1	7.5	2.7	0.0	12.2	± 1.11

Note.—

Eight replicates of 12 cuttings per plot. Measurements were made 21 days after setting.

Appendix IX. Hardening Trial.

—	Cuttings Satisfactorily struck and potted.
<i>In situ</i> hardening :—	
commenced 21 days after setting	22.1
commenced 25 days after setting	21.5
commenced 29 days after setting	21.8
Hardening in I.C.T.A. type bins	17.7 (5.9)
Standard Error	± 1.36

Notes.—

1. Ten replicates of 25 cuttings per plot.
2. The method of hardening in the I.C.T.A bins was similar to Harris's, except that bins were closed for the first five days with four applications of water per day. Lids were then gradually raised over a further five days and watering frequencies diminished to nil over this period. Basketed cuttings were removed from the hardening bins after another four days.
3. The figure in parenthesis represents the number satisfactorily struck and potted at the 21-day period.
4. Post potting losses were not significantly different between treatments and approximated 1 per cent.

Appendix X. Potting Soil Trial.

—	5 weeks after potting		9 weeks after potting		14 weeks after potting
	New leaves per plot	Non flushing cuttings per plot	New leaves per plot	Non flushing cuttings/plot	Dead cuttings per plot
3 parts black bush soil to 1 part com- posted sawdust mixture	6.2	7.8	16.5	4.7	1.5
As above plus fertilizer	15.8	5.3	20.8	3.0	0.7
Mimosa mulch	23.8	2.5	55.0	0.2	0.0
Mimosa mulch plus fertilizer	27.7	2.0	54.3	0.3	0.3
Standard Error	± 3.25	± 0.79	± 3.45	± 0.67	± 0.36

Notes.—

1. Six replicates of 10 cuttings per plot.
2. The fertilizer was a 6 : 1 : 2 N.P.K. applied at 2 oz. per cubic foot of the medium.
3. Cuttings were potted in baskets approximately 10 inches in height and 8 inches in diameter.
4. For a description of the black bush soil and mimosa mulch see the section "Potting".

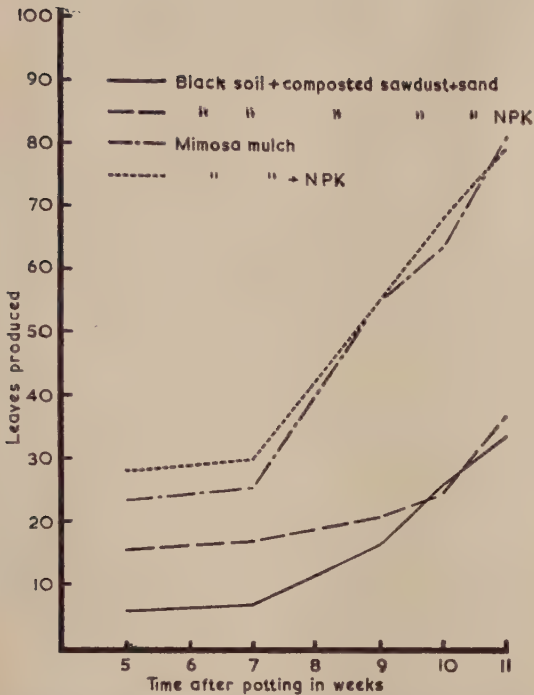


Fig. A7.—Potting soil trial—effects of different types of potting soil, with and without NPK fertilizer, on numbers of leaves produced by the cuttings.

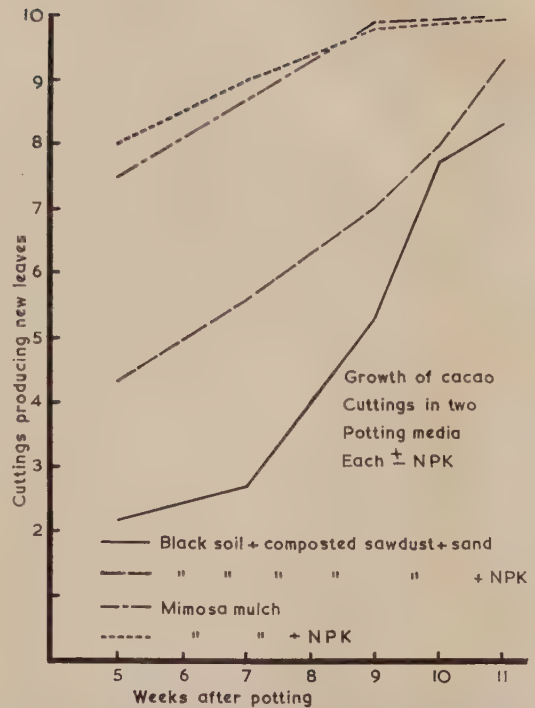


Fig. A8.—Potting soil trial—effects of different types of potting soil on time of initiation of new growth.

Appendix XI.

Comparison of Bamboo Tubes and Baskets as Pots for Cuttings.

	New leaves per plot
<i>Bamboo pots—</i>	
With a black soil/composted sawdust mixture	41.3
<i>Baskets—</i>	
With mimosa mulch	49.3
With a black soil/composted sawdust mixture	25.0
With mimosa mulch	59.2
Standard Error	± 2.63

Note.—

Six replicates of nine cuttings per plot. Measurements were made 13 weeks after potting.

MARGINAL CHLOROSIS, A SEED-BORNE VIRUS OF ARACHIS HYPOGAEA VARIETY "SCHWARZ 21" IN NEW GUINEA

BY R. J. VAN VELSEN *

Observations on the symptoms, effect on yield, and experimental data are given on the seed-borne virus disease of Arachis hypogaea variety "Schwarz 21" in New Guinea. Attempts at mechanical, soil and insect transmission were unsuccessful, but the virus was transmitted through cleft grafts from Schwarz 21 to Red Spanish, White Spanish, Schwarz 21, Virginia Bunch and Natal Common. The virus causes a severe stunting of the affected plants, with marginal chlorosis and crinkle of the leaves.

The yield of affected plants is reduced to half that of healthy plants. Control is readily effected by vigorous roguing at the flowering stage of all affected plants. The virus appears to be a new one previously undescribed and is tentatively named peanut marginal chlorosis.

THE condition was first recorded on Schwarz 21 in 1958 by Mr. K. Newton, in the crop-rotation trials at the Lowlands Agricultural Experiment Station, Keravat, New Britain District. Three per cent. of the peanut plants were affected. Preliminary mechanical inoculation experiments were carried out in 1958, but no transmission was recorded. In late 1958, diseased plants were again noticed in the rotation trials and seed was harvested from diseased plants and from neighbouring healthy plants. The collected seed was germinated in the laboratory in sterilized forest soil and observations carried out on the plants. Seed of both healthy and diseased plants germinated within seven days, and after 14 days seedlings from diseased field plants exhibited a marginal chlorosis of the leaves, and were smaller than seedlings from healthy plants. Subsequent leaves showed crinkle patterns on the leaves. The diseased plants were stunted, but were not rosette in habit. Investigations were then carried out to determine the cause of the marginal chlorosis and the leaf crinkle.

INVESTIGATIONS

Field Symptoms

The first sign of the disease in the field was seen two to three weeks after sowing. The leaves of the diseased plants exhibited a yellowing of

the leaf margin and a crinkling of the leaves. The plants were smaller in size than healthy plants and at maturity bore few nuts. The leaf symptoms were systemic and did not increase in intensity with age.

Effect on yield

Seed from diseased and healthy plants of Schwarz 21 was collected from the field and weighed. Results are given in Table I. From these results it is evident that the disease caused a severe reduction in yield compared with healthy plants.

Table I
Effect of Marginal Chlorosis on Yield of Schwarz 21.

Plant.	No. Plants.	Total Yield. (gm.)	Yield/Plant. (gm.)
Healthy	40	3,023	75.6
Diseased ...	40	1,326	33.2

Attempted Mechanical Transmission

Attempts were made to transmit mechanically the causal organism to disease-free ground nut plants of Schwarz 21 and Natal Common. The method of mechanical inoculation devised by Storey and Ryland (1955) was tried, but proved unsuccessful. Plants were etiolated for

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(Manuscript received 16th November, 1960.)

60, 72 and 96 hours, 200 plants being used in each test, but no transmission was obtained. Diseased plant material was ground in various composite buffers of strength 0.1M and pH 7.0. No transmission was obtained.

The following plants were inoculated with sap extracted from diseased Schwarz 21, *Nicotiana tabacum* var. White Burley, *Solanum dulcamara*, *Physalis floridana*, *Chenopodium amaranticolor*, *Vicia faba*, *Capsicum annuum*, *Nicotiana glutinosa*, *Lycopersicon esculentum*, *Crotalaria anagyroides* and *Arachis hypogaea* varieties Red Spanish, White Spanish, and Virginia Bunch. No transmission resulted.

Grafting

Diseased and healthy plants of Schwarz 21 were grown in sterilized forest soil in the laboratory and when 10 days old the tops were removed at the collar. Healthy scions were inserted onto diseased root stocks and diseased tops onto healthy root stock. A wedge-shaped graft was used. The plants were kept in a moist atmosphere for 48 hours and then placed in insect-proof cages. Observations were made 28 days after grafting. At the end of the observation period, 10 healthy scions out of 20 successful grafts were diseased and all 20 of the diseased scions remained diseased. A further experiment was set up using healthy scions of five different peanut varieties (Table II). The condition was transmitted to all five peanut varieties. The symptoms recorded on the diseased scions were the same as those recorded on Schwarz 21.

Table II

Transmission of Marginal Chlorosis of Schwarz 21 to Four Peanut Varieties by Grafting.

Variety.	No. Grafts Attempted.	Proportion of Plants Infected.
Red Spanish	18	3/15
White Spanish	18	1/17
Schwarz 21	18	6/17
Virginia Bunch	18	3/18
Natal Common	18	4/18

Attempted Dodder Transmission

Cuscuta campestris Yuncker was established on *Medicago sativa* and tendrils entwined around diseased plants of Schwarz 21. When appressoria were developed, the tendrils were severed

from the host plant. None of the appressoria became fully developed on the peanut plants, although 60 plants were used.

Seed Transmission

Seed was collected from 100 diseased plants in the field. The seed was then planted out and counts made on the number of diseased plants. Germination percentage was also calculated. The percentage of infected progeny from any one parent plant ranged from 31 to 100, with an average of 71. From the original 100 parent plants, 2,355 seeds were collected, of which 1,503 germinated (i.e., 63.8 per cent. germination). This compares with 89.0 per cent. for seed from healthy plants.

Insect Transmission

Wingless and winged adults of *Aphis craccivora* maintained on diseased Schwarz 21 in the laboratory failed to transmit the disease to healthy plants of Schwarz 21 and Natal Common, using the half-seed method adopted by Storey and Ryland (1955). Test feeding times ranging from 10 seconds to five days with and without pre-treatment starvation gave no transmission. Thirty seeds were used to each test.

Attempted Soil Transmission

There is no evidence in the field to suggest transmission of the disease through the soil. However, the possibility of transmission through the soil or by direct root contact was investigated. Infected seedlings of Schwarz 21 growing in the field were lifted with some of their surrounding soil and replanted in large containers. Ten seeds of known uninfected Schwarz 21 were planted in each container, but only five seedlings were retained. The plants were kept under observation for 28 days in insect-proof cages. Ten test pots were set. To eliminate possible insect transmission, the field plants were sprayed with 0.25 per cent. dieldrin. Before lifting, and after the seeds had been planted, the soil surface and plants were sprayed with this insecticide twice weekly. None of the 50 test plants grown developed the disease.

DISCUSSION

The above experimental evidence indicates that the marginal chlorosis and leaf crinkle of the peanut variety Schwarz 21 is induced by a plant virus. That the disease was not attributable to nutrition was indicated by the fact that

diseased and healthy plants were growing alongside each other. There was no evidence of the disease being caused by fungal, or bacterial organisms, nor by insects. As the disease is transmitted by grafts, the disease is not genetical. The virus is not transmitted by *Aphis craccivora*, nor by mechanical inoculation, but it is transmitted by seed and grafting.

Since no mechanical transmission was achieved, no physical properties or host range of the virus was determined. Storey and Ryland (1955) were able to transmit mechanically and by *Aphis craccivora*, ground nut rosette, using Natal Common as the test plants. In tests at Keravat, using the peanut variety Natal Common, no transmission was achieved except by grafting. Comparing the symptoms and methods of transmission of the virus causing marginal chlorosis of peanuts at Keravat with the viruses recorded on peanuts by Storey and Ryland (1957), it is tentatively concluded that this is a new virus previously undescribed.

The name peanut marginal chlorosis is suggested.

DESCRIPTION

Marginal chlorosis on *Arachis hypogaea* is a new virus disease previously undescribed. The disease is dissimilar to that of peanut rosette virus in method of dissemination and symptoms (Storey and Ryland, 1957).

Common name : Marginal Chlorosis of peanut.

Origin : *Arachis hypogaea* var. Schwarz 21, from Keravat, New Britain, Territory of Papua and New Guinea.

Host range :

Arachis hypogaea vars. Schwarz 21, Red Spanish, White Spanish, Virginia Bunch, Natal Common.

Distinguishing symptoms : Marginal yellowing, stunting of growth, leaf crinkle.

Transmission : Grafting and seed.

CONTROL

Since the disease appears to be transmitted only through seed, control is effected by the use of certified disease-free seed. Where diseased plants are found, these should be removed and burnt immediately to ensure that no seed is retained.

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- STOREY, H. H. AND RYLAND, A. K. (1957). Virus causing rosette and other diseases in Groundnuts. *Ann. appl. Biol.* 45, 318 - 326.

SUPPLEMENTARY FEEDING FOR CATTLE

J. F. S. BROWNE* AND D. E. MURRAY.†

IN this Territory conditions are in the main unsuitable for hay making as a means of conserving fodder for livestock. The lowlands regions do not support suitable plant species, while in the highlands weather conditions are unsuitable for hay curing. The humidity experienced does not make for good storage of hay.

Under such circumstances silage making is the only practical method of conserving fodder crops such as maize and sorghum, and excess grass growth. The succulence of the fodder is conserved and there is little loss of nutrients and digestible material. Unless moderate to heavy rain falls, weather conditions during silage making have little effect on the final product.

Chemical changes

During the process of converting green fodder into silage certain chemical changes take place. A brief explanation of these should assist the farmer in making a good-quality product.

When the green material is ensiled it is still alive and continues to take in oxygen and give off carbon dioxide until all air trapped in the silo has been used up. During the process heat is produced and the activity of bacteria and moulds is accelerated, acids being produced as by-products. Plant tissues are also broken down and the resulting chemical changes, assisted by the preliminary chopping and crushing of the material, improve palatability and digestibility. When all the trapped air has been used up by the plant material the moulds become inactive, although bacteria continue to live. At this stage sufficient heat will have been generated to kill the plant material.

Two main factors must be noted as causes of production of poor quality silage:—

1. If too much air is left in the fodder the temperature will rise too high. This overheating reduces the digestibility of pro-

teins. Also, the moulds, bacteria and plant material will remain active much longer, drawing on sugar reserves in the material to provide energy in maintaining their life processes, thus reducing the nutritive value of the silage.

2. The succulence of the material also affects the degree of heating and rate of acid production. Dry material is inclined to overheat and cannot be packed as well as sappy material. However, excess sappiness may cause spoilage in the silo unless provision is made for drainage or soaking up of excess liquid.

Silage crops

A wide variety of crops, as well as pasture growth, is suitable for ensiling. Maize and sweet sorghum, both of which grow very satisfactorily in most parts of the Territory, are regarded as especially suitable and provide a large bulk of good-quality fodder. In the Port Moresby area Elephant grass (*Pennisetum purpureum*) has been shown to give high yields of nutritious green feed. Other grasses, such as Guinea grass (*Panicum maximum* var. *trichoglume*) and Para grass (*Brachiaria purpureascens*), together with legumes such as *Centrosema*, may be expected to give a good-quality fodder in the silage pit.

Maize is best cut for silage when the cobs are well formed and the grains are filling but still milky. Sweet sorghum is cut when the heads are well out but the grain is still soft. Fair crops of both of these should yield 10 to 15 tons of green material per acre.

Harvesting is most conveniently done with a forage harvester, a reaper and binder, or a mower, but cutting with bush knives is satisfactory, although somewhat slower.

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If the material has dried off prematurely at harvest due to dry weather, the addition of molasses at the rate of about 40 lb. per ton of fodder will ensure reasonable-quality silage.

Silage storage

Silage can be stored in towers, trenches, stacks or clamps. The first-mentioned involves high capital costs in initial construction, and the last two are rarely used, other than for pasture silage, because of the amount of waste resulting from the large surface area in contact with the air.

Trench silage is a very satisfactory method of conserving fodder, and requires little capital outlay. The following points must be considered in the construction and filling of a trench:—

1. The trench should be excavated on high or sloping ground which is fairly well

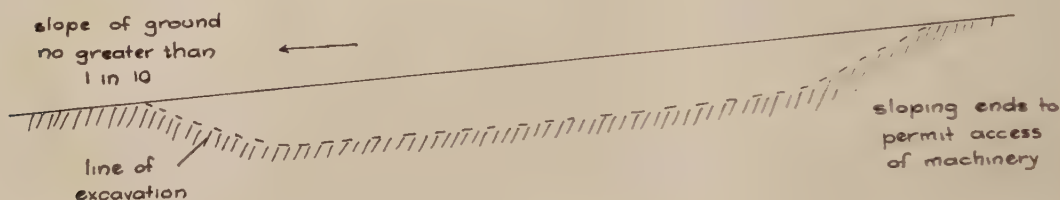
drained and where there is very little danger of seepage or of build-up of underground water.

2. Fairly long and narrow trenches are preferred to short, square types to facilitate packing of the fodder. The walls should be smooth and have a slight slope to the bottom to guard against formation of air pockets and to ensure a constant downward pressure of silage on them. The following dimensions may serve as a guide in the construction of trench silos:—

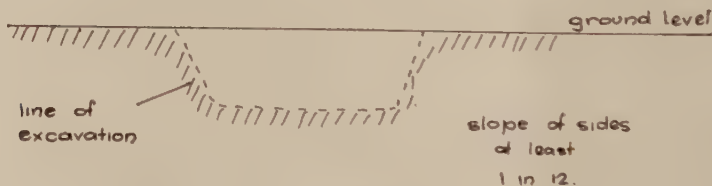
Width 12 ft., average depth 4 ft. and length—

- a. 40 ft.—approximately 35 tons capacity.
- b. 60 ft.—approximately 53 tons capacity.
- c. 80 ft.—approximately 71 tons capacity.
- d. 100 ft.—approximately 90 tons capacity.

Longitudinal Section



Cross Section



Sectional diagram of silage pit.

Two cubic yards of excavation hold about a ton of maize or sorghum silage.

Trenches of more than 100-ton capacity are not recommended, unless the operations are highly mechanized, because of difficulties, both economic and physical, involved in filling and feeding out.

3. In the filling of the trench, close and tight packing of the fodder is the primary consideration. Maize and sorghum are better chaffed, but if this is not possible, bundles should be laid down in closely-packed rows. The heads of bundles in each row should face in the opposite

direction to those in the preceding row, and each row should overlap the preceding one by half the length of the bundle. Stacking is continued like this, keeping the centre of the pit slightly higher than the edges. When the first two or three feet have been laid in the bottom of the pit, the tractor should be run through several times to assist in packing, and then the material left overnight to ensure that heating is commencing properly. The correct temperature is 85 to 90 degrees Fahrenheit. If there is no rise in temperature, filling operations must be delayed. When the temperature has risen to the correct level, further compaction with the tractor is done to discourage any further temperature rise in this layer. Then filling may proceed in two to three-foot layers, allowing each layer to reach the desired temperature and compacting it before adding the next layer.

4. When the filling has reached ground level, the green material should be allowed to extend a few inches outside the wall of the trench. This will ensure that as the silage sinks under the pressure of additional material, it will be compressed firmly against the walls of the trench. Additional green material should be heaped and compacted to a height of about four feet above ground level.

A slow rate of settling indicates good packing. The importance of filling and packing cannot be overemphasized. As the stems soften during heating the weight of material above presses down until a compact mass results.

5. Two or three days after the final stacking earth is scooped on top of the material until there is a cover of nine to 12 inches. A layer of green grass may be added before covering to reduce waste, as the top few inches will have to be discarded when the trench is opened. After covering, the area must be watched closely and any depressions or cracks which may collect water should be filled in. Surface drains should be constructed to prevent water from lying in the area of the trench.

Feeding the Silage

On exposure to the air silage begins to deteriorate. Thus, the aim in feeding silage out of the silo should be to expose the least possible area of the surface of the silage remaining in the silo.

The usual method in feeding from trench silos is to open at one end, removing sufficient earth to permit a week's feeding. The silage is then cut down in a straight vertical wall across the pit, and is removed in layers.

On opening the pit the silage should be a compact mass and light-brown to olive-green in colour. A dark, charred product is indicative of poor consolidation in the trench, while a rather slimy and smelly "sour" silage results from underheating due to the laying down of very wet material or accumulation of water in the pit.

The hay knife and the axe or broadaxe are the most favoured tools for cutting silage from the pit. Many farmers have devised and improvised cutting tools to suit their own needs, ranging from old chaff-cutter blades to small chain saws. Self-feeding from the pit has not been successful, due to wastage and slush on the trench floor.

Good silage is very palatable and cattle will eat up to 80 lb. per day. For supplementary feeding of milking cows on poor pastures, about 50 lb. of silage per day plus crushed grain and a protein concentrate is recommended. When dry cows and beef cattle are on poor grazing, silage fed at the rate of 20 to 40 lb. per day will help maintain the condition of the stock.

The quantity of fodder to be ensiled as a reserve for supplementary feeding during the dry period when there is very poor pasture growth can be calculated at the rate of one-half to one ton per beast per month.

Silage making in Papua

Silage has been put down in trenches on several occasions in Papua, with varying degrees of success. The failures have been due mainly to waterlogging and faulty compaction in the pit.

In 1959, approximately 700 tons of silage was made at the Papuan Lowlands Livestock Station, Moitaka, for supplementary stock feed during the dry season. This was all put down in one pit which measured about 75 yards by five yards,

by three yards deep. This trench is much larger in size than is usually recommended, a circumstance made possible by the heavy equipment available.

The material ensiled consisted of 15 acres of maize, giving an estimated yield of 16 tons to the acre, 25 acres of Kavirondo sorghum (*Sorghum verticiflorum* var. *Kenya*), a non-toxic grazing variety, giving about 10 tons per acre, and 28 acres of volunteer Kavirondo growth yielding from four to eight tons per acre.

Nearly half the area was cut with a side-blade mower, the rest being cut by hand. The material was carted to the pit in trucks and unloaded and spread by natives. Compaction was done by the full-time use of a crawler tractor as the material was placed in the pit.

As each six to eight inches of silage was compacted it was watered with a mixture of equal parts of water and molasses at the rate of four gallons per ton of silage. This was done to stimulate microbial activity in the material which has a sugar content rather below the optimum for silage processes.

The pit was filled to a height of four feet above ground level, and left for five days, during which time it settled about two feet, indicating fairly good initial compaction.

An 18-inch layer of soil was spread over the top to exclude air and shed water from the pit. A fortnight after this sealing, two low spots were filled on the earth cover and drains were cut around the pit to assist run-off of water.

The actual filling of the pit took 17 working days using a labour force of two Europeans and 30 natives. So, using reasonable equipment, the filling of a 100-ton-capacity trench should be easily completed in one week.

When the trench was opened for feeding, the silage was of good, greenish-brown appearance. Chemical analyses indicated a content of 5 per cent. crude protein which is about half the usual figure for high-quality silage. The crude fibre figure of 35 per cent. was approximately normal.

The silage was very palatable to the cattle, both beef and dairy types, and proved invaluable as a supplementary feed to carry the stock over the abnormally-long dry season experienced in the Port Moresby area in the latter half of 1959.

OBSERVATIONS ON THE BANANA SCAB MOTH IN THE TERRITORY OF PAPUA AND NEW GUINEA

BY R. W. PAINE.*

The writer spent nearly two years in the Territory collecting parasites of Banana Scab Moth for introduction to Fiji. This work was based on Lae from November, 1956, to February, 1958; and on Rabaul from May to September, 1960. Four weeks, altogether, were spent on Bougainville in June and October, 1960.

Distribution of the Species

THIS well-defined species of Pyraustine Moth ranges from Samoa in the east to Sumatra in the west. There is no appreciable variation between individuals from widely-separated islands, nor in those from different food plants. There is a tendency for individuals in the western part of its range to be slightly darker in wing colour than those which occur in Fiji, and perhaps in other Pacific Island groups, though this does not seem to be a consistent feature.

There is no confirmed record of its occurrence north of the Equator except in Malaya, Sumatra, Borneo, Celebes and certain other islands of eastern Indonesia. Between the Tropic of Capricorn and the Equator its insular distribution is probably total, except on islands where none of its food plants occur. In Australia it is found on the Queensland coast from Cardwell to Daintree. It may even occur along the northern coast of Australia on pandanus though this has not been checked.

Local Food Preferences and Host Plants

Nacoleia octasema has so far been found to have four principal food plants: banana (cultivated and wild); *Heliconia* (Musaceae); *Pandanus* and Nipa Palm. Although these plants are not particularly closely related they all possess a certain quality of inflorescence which provides a similar type of food and habitat for the thin-skinned larvae.

It is noteworthy that in certain islands one or more of these plants may occur, but are not fed on at all by the Scab Moth. In Table I a summary is shown of what information is now available concerning the food plant in some parts of the Territory of Papua and New Guinea. The most important result of its food preferences so far as the Territory is concerned is the fact that up until now no single instance has been observed of any feeding on bananas on the New Guinea mainland. This large island seems, in fact, to possess an advantage for the commercial production of this crop in that there would be no damage from Scab Moth. Compared with New Britain and Bougainville this advantage is a very striking one.

Economic Status of Scab Moth on New Britain and Bougainville

It has been estimated that in Fiji one-quarter of the banana crop is damaged by Scab Moth. In my survey and collection of this pest from bananas in New Britain and Bougainville I would estimate damage of potential crop to be comparable with that in Fiji. Since bananas are grown only for local consumption and with so little trouble in the Territory, no attempt is made to control the Scab Moth: sufficient fruit is grown to meet local needs in spite of much that is discarded on account of Scab Moth damage.

Only occasionally were clean, undamaged bunches met with; though, as in other places, if prolonged periods with little rain occur Scab

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Table I.

Records of *Nacoleia octasema*, Meyr. on different food plants in Territory of Papua and New Guinea.

Islands and District	Cultivated Banana	Musa spp. (Wild Banana)	Pandanus (one or more sp.)	Heliconia (one or more sp.)	Nipa fruticans.
New Guinea: Morobe, Madang Papua: Central, Highlands	Absent	Absent	Present	Present	Doubtful
New Britain: Gazelle Peninsula	Present	....	Present	Present	....
New Ireland: Kavieng, Lelet ⁴	Present	....	....	....	....
Bougainville: Kieta, N.W.	Present	Present	Present	Present	Absent
Buka: S. and S.E.	Present	....	....	Present	....
Umboi: (Rooke Island)	Present	....	....	....	Absent
Malai: (Siassi Island) ¹	Present	....	Present	....	....
Samarai	Absent	....	Present	...	....
Manus ²	Absent (?)	....	....	..	....
Woodlark ³	Absent	....	...	....	....
Manum ³	Absent	....	....	....	...

¹ A single empty pupal skin believed to belong to *N. octasema* is all that was found in some dozen inflorescences cut from the coast of Papua.

² The record from Manus is based on the examination of only eight banana bunches during a very brief survey near the airport.

³ Records from Woodlark and Manum were received respectively from the Commonwealth geological party, 1960, and from the Government Vulcanologist, Territory of Papua and New Guinea. These islands were not visited by the writer.

⁴ Specimens were seen in the collection of Mr. W. Brandt from Lelet Plateau.

NOTE:—Where there is no entry either no search was made, or else the host plant in question was not found.

Moth damage tends to diminish. In Queensland, and also in certain parts of south-eastern Indonesia, the dry season is sufficiently well marked to bring about an almost total seasonal control of the pest. In New Britain, where I was collecting in January and February, 1958, and again from May to September, 1960, there was never any period when damage by Scab Moth to bananas was insignificant, though it is at its worst during the wetter months of the year.

Controlling Factors

Apart from the rather enigmatical reduction of population induced by drought conditions, very few important controlling agencies have been discovered. At certain times it seemed that ants and perhaps also birds took toll of the larvae, though the evidence was never more

than circumstantial. Of parasites, the following species appeared in relatively small numbers in most collections of the early stages of the Moth.

- (a) *Pentalitomastix nacoleiae* Eady (New Guinea only)—larval parasite.
- (b) *Sabatiella* sp. (New Guinea and New Britain)—pupal parasite.
- (c) *Goniozus triangulifer* Kieff.—larval parasite.
- (d) *Bactromyia fransseni* Bar. (not found on Bougainville)—larval parasite.
- (e) *Sisryopa* sp. (not found on New Guinea: abundant locally on Bougainville)—larval parasite.
- (f) An Ichneumonid (not yet identified)—larval parasite. (This appeared only on Bougainville, where it was locally abundant.)

Several other species of parasites were bred but in very insignificant numbers. No collections were made on New Ireland.

Quarantine Considerations

The fact that Banana Scab Moth feeds on bananas in New Britain and Umboi, but not in New Guinea and certain of its off-shore islands, suggests that steps might be taken to prevent the introduction to New Guinea of what could be described as the "banana-feeding strain" of the moth. But in considering this it is important to realize certain facts concerning the habits of the insect.

Adult moths seldom, if ever, fly to a light. The incubation period is usually three and a half days to four days and the eggs are laid only on fresh green leaves. If they should be removed from proximity to their food (viz., a newly-opening banana bunch) it is very unlikely that they would find other food before they died.

Larvae feed for only the first two weeks after a new bunch opens; rarely any longer than this. They are, therefore, never present on fruit which is ready for harvesting.

The pupae, which require 10 days to develop after the cocoon is first formed, could, under certain circumstances, be transported in live condition. They occur most usually in the tunnel which forms along the leaf petiole after the leaf withers. They also occur beneath the fibrous dead leaf-bases where they encircle the pseudostem of the plant; also, occasionally between individual fruits in a bunch. In the last-named situation, however, moths would have emerged long before the bunch would be ready for cutting.

The risk of transporting living Scab Moth material during normal commercial and private transactions is thus seen to be a very small one. Occasionally dead banana leaves are used for wrapping purposes and this practice should be at least discouraged, since it affords about the only way of accidentally transporting the live insect.

PANTORHYTES CONTROL IN CACAO PLANTATIONS

By the Entomology Section, Department of Agriculture, Stock and Fisheries.

THE cacao weevil borers (*Pantorhytes* spp.) are now firmly established as major pests of cacao in the Territory of Papua and New Guinea. Five different species have so far been recorded from cacao and these occur in seven different districts.* It is, however, only in New Britain, the Markham Valley and the Northern District of Papua that the incidence of the weevil is sufficiently high to cause severe damage. The known habits of the different species indicate that similar control measures should be adopted for each species.

Cacao growers can prevent or reduce weevil damage by following recommended cultural and clean-up practices and by using insecticides.

Pantorhytes is not an introduced insect. Before the advent of cacao growing, the weevil was confined to native host plants in primary and secondary forest. It has, however, adapted itself very satisfactorily to cacao and this can now be regarded as one of the major host plants in the Territory. In areas where cacao is not already established as the host, it should be possible to reduce considerably the build-up of the populations by strict plantation hygiene. Basically, this involves the removal of native host plants from the vicinity of plantations and the concentrated treatment of already infested areas to prevent the further spread of the weevil.

Development

The weevil is a serious pest in all months of the year, although there may be minor seasonal or annual fluctuations in the incidence and severity of damage.

It has four stages in its development—egg, larva (grub), pupa (resting stage) and adult.

The length of the life cycle from the egg stage through the larva, pupa and adult to the following generation varies from none to 16 months.†

* *P. plutus* Oberth. from New Britain, New Ireland and Milne Bay; *P. proximus* Fst. from the Markham Valley; *P. szentivani* Mshl. from the Northern District of Papua; *P. biplagiatus* Chev. from Bougainville; and *P. quadripustulatus* Gestro from the Sepik District.

† The life histories of all species have not yet been fully studied and the durations of the stages given here are approximations based on studies with *P. proximus* and *P. plutus*.

Egg

The female adult lays her eggs in the cracks and crevices on the bark of the trunk, usually at or below the jorquette. Trees under about three years are not generally attacked, because the bark at that stage is not sufficiently roughened to provide a suitable egg-laying site for the weevil.



Fig. 1.—*Pantorhytes proximus* Fst.
Larva. (4 x Nat. Size.)

[Drawing by M. L. Szent-Ivany.]

Larva

The larva is typical of weevils and has a well-developed head and a robust, curved body which lacks legs. (Figure 1.) The body is regularly wrinkled and has rows of fine hairs. The head is hard and brown and there is a well-developed mouth. The larvae hatch from the egg after about 14 to 18 days and they grow to about

three-fourths of an inch long by a series of moults at which they shed their skin as it is outgrown. From available evidence it appears probable that larval development is more rapid in quick-growing native host trees than in cacao, which is a comparatively hard-wooded tree.

Pupa

After nine to 16 months, the larva is fully developed and it stops feeding and enters the resting stage or pupa. This pupal stage is spent in a hollowed-out cell beneath the bark of the tree. It is at this time that the larval tissues break down and the body undergoes a change to the form of the adult, which eventually becomes visible through the pupal skin. The pupal stage lasts for about 15 days.

Adult

The colour and form of the adult weevils vary with the different species. However, all species are about one-half to five-eighths of an inch long. They have a well-developed head and thorax and an abdomen which is strongly rounded and tapers sharply at the rear. (Figure 2.)

All *Pantorhytes* species are unable to fly, but their well-developed legs enable them to move reasonably rapidly when disturbed. Frequently, when approached, they drop from the trees and withdraw their legs into their bodies and appear to feign death.

This flightless characteristic of *Pantorhytes* should be utilized by planters when devising methods of control. It should be possible to protect cacao areas by providing a barrier to the movement of weevils. The only way that *Pantorhytes* can get into a new cacao area is by walking or by human agency. By eradicating alternative host plants around the perimeters of cacao plantings, the distance to the new host can be a deterrent to the spread of the weevil.

Damage

Most *Pantorhytes* damage is done by the larvae, although the adults may cause minor damage to the bark of the young shoots on which they feed. This superficial feeding is not very important and the adults apparently do not damage the plant enough to reduce yield or to set back the trees.



Fig. 2.—*Pantorhytes szentivanyi* Mls.
Adult. (4 x Nat. Size.)

[Drawing by M. L. Szent-Ivany.]

The larvae generally attack the tree in the region of the jorquette, but they are frequently found also in the branches, particularly of older trees. In the trunk, the tunnels are usually straight, but in the smaller branches ringbarking may occur, with the subsequent death of the limb. Feeding is confined to the sap-wood and considerable amounts of frass are produced as evidence of attack. The tree usually reacts by producing quantities of a gummy exudate which issues from the borer hole and which, in some cases, may effectively immobilize the larva and prevent its further development.

Control measures

Investigations into the control of *Pantorhytes* are continuing at different Territory centres, but meanwhile planters can prevent or greatly reduce weevil damage by following the procedures outlined below.

Eradication of alternative host plants

As stated before, cacao is not the natural host plant of *Pantorhytes*, and in new areas it must gain access to plantations from native host trees

adjacent to the plantations. Some of these indigenous hosts have already been determined, but there are undoubtedly other unknown species occurring in different areas. The most important known host is *Pipturus argenteus* (Forst.) Wedd., a common regrowth species through-

out the Territory (Plate I). *Pipturus* is one of the first species to appear on cleared land, but is soon overshadowed and outgrown by taller species if the secondary growth is allowed to go unchecked.



Plate I.—*Pipturus argenteus* (Forst.) Wedd.

[Photo D. Shaw.]

The tree is rather small, growing about 20 to 30 feet high. The leaves are dark-green above and whitish below. They are spade-shaped and have a serrated margin.

There are three conspicuous longitudinal veins, of which the outer two are less prominent than the central one. The flowers are small and grouped in pale-green globular clusters at the junctions of branches. The fruit is rather similar to a small, white strawberry.

Another naturally-occurring host tree is *Schuermansia benningii* (K. Schum). This

tree seems unable to tolerate flat ground with poor drainage, although it demands abundant soil moisture. It may be found on flat places on the edges of terraces and gullies, but it usually inhabits steep slopes.

Schuermansia is a tall shrub or small tree reaching about 30 feet in height, with a trunk to about six inches in diameter. The branches are thick, brittle with a central pith. The leaves are clustered at the ends of branches and they are pale-green in colour and lack stems. They are very long—up to 30 inches—and up to

five inches broad, with the widest part near the tip. The flowers are pink in colour and very numerous, forming a long, loose panicle about two feet long.

It is important to remember that *Pantorhytes* can only come into new cacao areas from its indigenous hosts in the surrounding forest. Knowing where the weevil comes from and where to expect an invasion of pests helps considerably in its control. Known native host species should be slashed and brought under control within a workable distance from the plantation or grove. Sustained control is possible by the use of cover crops, and selective thinning of secondary growth to keep down *Pipturus* and *Schuurmansia*. To be effective it is necessary to slash down the host trees at about six-month intervals so that the larvae do not have time to complete their development.

Control within Cacao Plantings

In areas where *Pantorhytes* is a serious problem, it is advisable to have a team of perhaps two or three labourers who are permanently engaged in the control of the pest.

Larvae

Attention should be paid to the destruction of larvae in the trees wherever they are seen. Sometimes it is possible to remove the larvae with a sharp knife, but with older larvae this practice is very damaging to the trees, and is generally not worth while.

Adults

Experiments in the control of *Pantorhytes* adults have been proceeding for several years, but no cheap and effective control recommenda-

tion has yet been devised. In small areas, it is often practical to have labourers collecting the adults by hand and then destroying them. A bonus system may be employed to induce better results.

The use of sticky bands incorporating an insecticide has been contemplated and, although effective, it is far too uneconomical to consider on a plantation scale. Future work may result in the development of newer and cheaper materials which may be applied to trees on the borders of plantations to prevent infestation from natural host trees.

Several insecticides have been used in sprays against the adult weevils and present indications are that D.D.T. is the most effective material. In the Markham Valley 0.5 per cent. D.D.T. applied in high-volume sprays considerably reduced the weevil population when applied at six-week intervals. Experiments in New Britain with D.D.T., using power-driven, low-volume sprayers indicate that 10 oz. D.D.T. per acre applied at two-month intervals will also exert good control. The success of a spraying programme depends upon constant supervision to ensure that the insecticides are applied thoroughly and evenly over the affected area.

When considering *Pantorhytes* control, it is important to remember that prevention of infestation is much easier to attain than eradication, once the pest has become established. The removal of alternative host plants and the establishment of a barrier to the passage of the weevils is a very necessary part of plantation hygiene in those areas where *Pantorhytes* occurs.

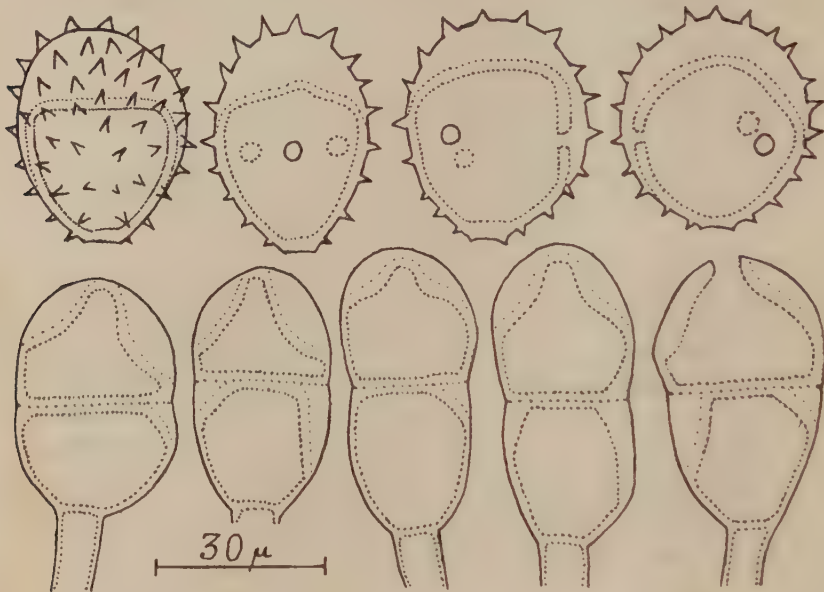
A NEW RUST ON FINSCHIA CHLOROXANTHA IN NEW GUINEA

BY GEORGE B. CUMMINS.*

Puccinia finschiae Cummins sp. nov. is described on *Finschia chloroxantha* Diels † from New Guinea.

Puccinia finschiae Cummins sp. nov. Fig.

Urediiis hypophyllis, laxe aggregatis vel sparsis, usque ad 1 mm. diam., cinnamomeo-brunneis, pulverulentis, paraphysibus nullis; urediosporis (23-)27-33(-35) x (30-)33-40(-45) micron, globoideis vel late obovoideis, membrana (1.5-)2(-3) micron crassa, aureo- vel cinnamomeo-brunnea, ad apicem (5-)7-12(-15) micron crassa et pallidiore, valde aculeata; poris germinationis 2(?) vel 3, equatorialibus. Teliis urediis conformibus sed compactis; teliosporis (24-)26-30(-33) x (40-)44-55(-58) micron, plerumque oblongo-ellipsoideis, membrana 1-1.5(-2) micron crassa, ad apicem 5-8 micron crassa, pallide aurea, levi; pedicello hyalino, fragili, usque 50 micron longo; statim a maturitate germinantibus.



Urediospores (above) and teliospores (below) of *Puccinia finschiae*.

The urediospores are golden brown with the outer wall paler and the teliospores are golden brown and germinate without dormancy.

Type: On *Finschia chloroxantha* Diels, Korn Farm, Mount Hagen, New Guinea, 19 Nov. 1959, Smythe, comm. D. Shaw TPNG No. 2586b (TPNG, IMI, PUR).

The wall of the urediospores is mostly distinctly bilaminar, with the inner layer thin and the outer much thickened over the germ pores and apically. Basally, the outer layer is absent or much reduced.

This is the first species of *Puccinia* and one of the few rust fungi reported as parasitizing the Proteaceae.

* Department of Botany and Plant Pathology, Purdue University, Lafayette, Indiana, U.S.A.

† Identified by Mr. J. Womersley, Division of Botany, Department of Forests, Lae, Territory of Papua and New Guinea.



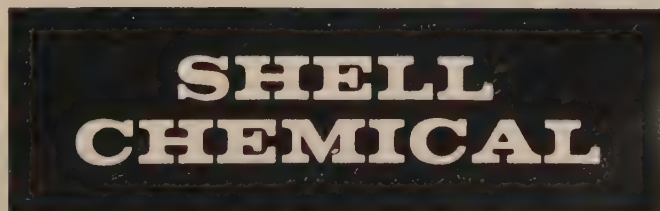
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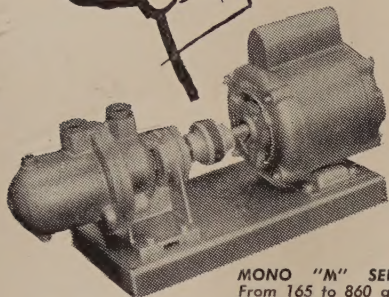
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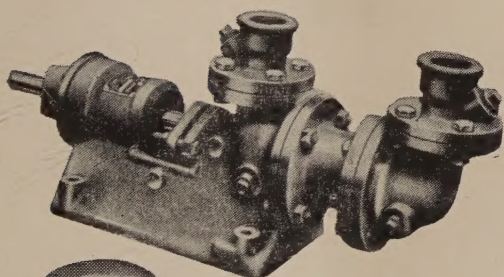
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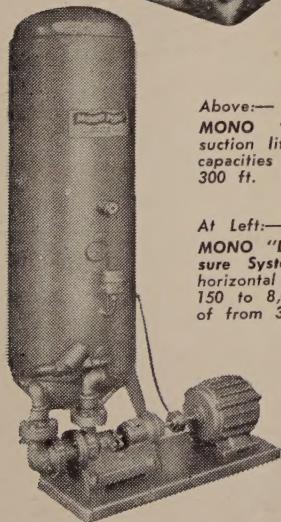
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